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Bezeichnung: Service vehicle for performing in-space operations on a target spacecraft, servicing system and method for using a service vehicle

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Die angehefteten Stücke sind eine richtige und genaue Wiedergabe der ursprünglichen Unterlagen dieser Patentanmeldung.

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Claims

1. Service vehicle (6) for performing in-space operations on a selected target spacecraft (2), comprising a communication module (60) which with respect to its transmission characteristics is configurable in order to meet given receiver parameters of said selected target spacecraft (2).
2. Service vehicle (6) according to claim 1, wherein said configurable communication module (60) comprises a transmitter (66).
3. Service vehicle (6) according to claim 1 or 2, further comprising a control module (68) for providing a setpoint for an output power of said configurable communication module (60).
4. Service vehicle (6) according to claim 3, wherein said control module (68) inputwise is connected to a first position sensor, said first position sensor delivering a set of data characteristic for the current position of said service vehicle (6).
5. Service vehicle (6) according to claim 4, wherein said control module (68) inputwise is connected to a second position sensor, said second position sensor delivering a set of data characteristic for the current position of said target spacecraft (2).
6. Service vehicle (6) according to one of the claims 3 through 5, wherein said control module (68) inputwise is connected to an orientation sensor, said orientation sensor delivering a set of data characteristic for the current orientation of said target spacecraft (2) in relation to said service vehicle (6).
7. Service vehicle (6) according to one of the claims 1 through 6, further comprising a docking system (24), said docking system (24) comprising a hollow first axle (40) insi-

de of which a second axle (42) is moveably disposed, said second axle (42) carrying an activateable arrow tip (46).

8. Service vehicle (6) according to one of the claims 1 through 7, further comprising means for identifying said target spacecraft (2).

9. Servicing system (1) for providing in-space service operations to a selected target spacecraft (2), comprising a service vehicle (6) according to one of the claims 1 through 8, and further comprising a ground control module (12) for delivering operational commands to said service vehicle (6).

10. Servicing system (1) according to claim 9, wherein said ground control module (12) is set up to receive data from said service vehicle (6) by using said target spacecraft (2) as a relay station for signals emitted from said service vehicle (6).

11. Servicing system (1) according to claim 9 or 10, further comprising an orbit-based utility base (4) for said service vehicle (6).

12. Servicing system (1) according to one of the claims 9 through 11, further comprising a relay module for forwarding transmitted signals to said service vehicle (6).

13. Method for in-space servicing of a selected target spacecraft (2), wherein a service vehicle (6) according to one of the claims 1 through 8 is used to perform selected in-space operations on said target spacecraft (2), and wherein operational signals from said service vehicle (6) are transmitted to a ground control module (12) by using said target spacecraft (2) as a relay station for said operational signals.

Description

The invention relates to a service vehicle for performing in-space operations on a target spacecraft. It furthermore relates to a servicing system and to a method for in-space servicing of spacecraft.

Spacecraft in general need to be properly positioned in a predetermined orbit and be properly oriented in the three-dimensional space with respect to their service areas in order to fulfill their respective mission. In other words, they typically are designed to have their telecommunication equipment looking to (or pointing to) the service area. Various forces such as moon gravity, sun gravity, non-uniformity of gravity potential of earth, solar pressure, and atmosphere in low altitudes, and even Venus gravity, plus many other less important forces, interact with the spacecrafts and tend to change their optimum position and orientation. These sources alter the orbital elements of the respective spacecraft effecting what is called orbit perturbations. To counteract these perturbations, spacecraft are provided with thrusters, which are used either in continuous mode or in pulse mode or occasionally, from time to time (i.e. every a few days/weeks/months). Said thrusters consume fuel in order to effect the counteracting forces.

Artificial satellites are a particular case of spacecraft as their mission involves orbiting a specific celestial body in order to be able to provide their service. Other spacecraft have trajectories that may differ for part of their mission from the classical definition of satellite orbiting but still have a service area where they have to point to and accordingly may be negatively influenced by similar perturbations. Usually they become satellites of another celestial body or simply float in space at a Lagrange point or elsewhere. The same nature of problems pertains to all type of spacecraft as regards their orbit and health issues. For reasons of clarity, the following description focuses on a satellite in the proximity of earth and in particular in a proximity that teleoperation capability is not hindered by long electromagnetic wave propagation times, although the concepts may also be relevant to other kinds of spacecraft.

A spacecraft that can be kept, by means of its thrusters, in a desired target position and attitude is considered under control or controllable, and a non-controllable spacecraft is out of control with regard to its position and attitude. Said controllable spacecraft can be

1 more easily and safely approached for servicing, and is called "co-operative", while a
2 spacecraft that has lost its attitude control is called "non co-operative".

3
4 Typical spacecraft are designed for a so-called "designed lifetime". The "designed lifetime"
5 of a spacecraft has a statistical definition. Spacecraft are designed to have an operational
6 lifetime of e.g. 10 years at minimum, with an associated probability 98% (based on
7 the statistical lifetime of the selected components). This means that in the term of 10 years
8 a portion of 2% of the spacecrafts of the same design and material and processes
9 would fail and the rest would continue to function. The average lifetime of the materials of
10 a spacecraft is much longer, sometimes 3 times the "designed lifetime". For example, the
11 voyager spacecraft still operate after 25 years, while most of the telecommunication satellites
12 have a designed lifetime of 6 to 15 years.

14 The spacecraft are designed to carry a predetermined amount of fuel, which is calculated
15 in dependence of what they would need to consume during their "designed lifetime". Consequently,
16 a spacecraft carries fuel only for the designed lifetime (e.g. 10 years) in order
17 to perform all types of maneuvers. At a certain point of time, when fuel reserves finish, a
18 spacecraft cannot retain even its attitude correct and so it becomes useless.

19
20 When the fuel reserves are very limited, then the spacecraft can no longer provide the
21 same level of service that it was designed for, or even provide any useful service at all. In
22 this case the spacecraft is rendered useless and abandoned in space creating an additional
23 problem of potential collision with a future operational spacecraft. It becomes as it is
24 called „space debris“.

26 Fuel-depletion that renders the spacecraft uncontrollable and therefore useless, may
27 happen even earlier than the designed lifetime of the spacecraft for various reasons (e.g.
28 simple bad calculation of the fuel budget, wrong positioning due to error, malfunctioning
29 of the launcher, rare phenomena, accident or otherwise, during the launch phase; wrong
30 positioning of the spacecraft during the LEOP (Launch and Early Orbit Phase) due to error,
31 malfunction, rare phenomena, accident or otherwise; change in mission; errors, malfunctions,
32 rare phenomena, accidents, or otherwise during the remaining actual lifetime).

34 In general, any component, unit, subsystem of a spacecraft, such as sensors, actuators,
35 processing units, inertial subsystems, power subsystem, software, communication pay-

1 load, may fail due to errors in its use, malfunction, rare phenomena or otherwise that may
2 render the spacecraft partially or totally, temporarily or permanently uncontrollable and
3 therefore unable to function properly to generate the opportunity revenue, or any revenue.
4 It may even create a significant risk for other spacecrafts by its status as space debris. In
5 this definition of space debris we will add to the traditionally conceived one, that regards
6 space debris as passive objects, the characteristic of potentially active object that may be
7 even more dangerous than a passive debris, as an active and unpredictable (accelera-
8 ting, decelerating) moving object may be.

9
10 For both reasons, i. e. lifetime restrictions due to limited fuel resources as well as system
11 failure due to unexpected error, servicing capabilities for spacecraft with the general goal
12 of artificially extending the lifetime of a spacecraft are highly desirable, particularly in
13 view of the typically very high costs involved with replacing an existing spacecraft by a
14 substitute.

15
16 Several inventions have been developed for solving the problem of providing servicing
17 capabilities for spacecraft, particularly with respect to failure on satellites and fuel-
18 depletion (US 5,410,731, US 5,813,634, WO 0103310), disclose concepts to inspect the
19 satellites on orbit (US 6,296,205, US 6,384,860), disclose concepts to provide service to
20 them on orbit (WO 9731822, US 4,896,848, US 4,273,305, US 5,299,764, US 4,349,837),
21 or prepare for servicing (US 4,946,596, EP 1 101 699, US 4,657,221). Several others
22 have developed concepts for tools to perform the service (US 4,177,964, WO 0208059)
23 or developed methods for providing new services (EP 1 245 967) for which this invention
24 provides improvements.

25
26 Various systems have been studied, wherein the method for performing the rendezvous
27 typically is carried out by manual Tele-operation. In some other documents, autonomous
28 rendezvous and docking systems are proposed.

29
30 In the case of autonomous docking mechanisms, the designs that have been proposed
31 involve a robotic arm which demands high dry mass and power budgets.

32
33 Patent US 5,299,764 discloses a system for carrying out in-space servicing of spacecraft,
34 wherein artificial life robotics are utilized.

Patent US 6,296,205 discloses a concept of inspecting the RF functioning of a satellite at proximity and emitting control signals and diagnostics to the ground.

Patent US 6,384,860 discloses a video telemetry system for monitoring the deployment of an apparatus coupled to a satellite. This allows the solar panels to be observed during deployment and even before said panels are deployed, but at very low rate (one frame every 27 seconds), said rate not permitting any real teleoperation and any other service.

In the cases where teleoperated designs of service vehicles are proposed these are disadvantaged by the high bandwidth required from the service vehicles to support the teleoperation. To perform an inspection or rendezvous and docking to a satellite a high bandwidth link needs to be established for certain minutes or hours in order to provide sufficient and timely (real time) visual information to the operators and systems on earth to perform the servicing (inspection, rendezvous, docking). Such designs have been proposed resulting in the GSV Geostationary Service Vehicle concept spacecraft.

The disadvantages of this category of prior art are:

- High electric power budgets, in order to cope with the required high bandwidth transmission for transmitting timely (in real time) the output of the rendezvous sensors (radar, visual images) towards the ground stations.
- High mass budget for the Mission Communication payload, batteries, solar cells, plus structural overhead and overheads to the attitude control subsystem (flywheels, thrusters...).
- High volume as result of the above increased budgets (mass, structural overhead, protruding antennas, protruding solar panels).
- High complexity due to the redundancy required.
- Higher vulnerability to radiation hazards and debris (larger profile).
- Low range of operation as regards delta velocity potential.
- Large consumption of consumables (fuels, pressurization gas).
- Low maneuverability due to high volume and mass.
- Higher risks of client due to higher mass and volume and lower maneuverability.
- Larger debris problem at end of its life.

The complexity of service missions to orbiting satellites and the high cost involved (space shuttle cost is 500 M\$ per flight) has rendered the idea of servicing ailing satellites as a

1 solution to restore or prolong service unattractive. As an alternative, putting into orbit uni-
2 versal back-up satellites or specifically designed, individual backup satellites is consid-
3 ered.

4
5 The Geostationary satellites in order to reach their orbit need to use some kind of launch
6 vehicle of which vehicle either the last part (upper stage) or the apogee kick motor is jetti-
7 soned in the space close to the geostationary ring creating space debris. Said debris con-
8 stitutes a high hazard potential for future missions. Some recent satellites use a Unified
9 Propulsion System for reaching geosynchronous orbit from their injection point and for
10 orbit maintenance. This solution saves one piece of debris but results to higher mass
11 overheads for the duration of the entire life of the satellite. At the end of life of the satellite
12 the totality of it becomes space debris.

13
14 Up to now, almost no spacecraft has been designed to be refueled or be serviced in
15 space. As one result of this design philosophy, a large part of space debris consists of
16 spent spacecrafts and apogee kick motors and upper stages.

17
18 Therefore, it is an object of the present invention to provide a particularly versatile and
19 flexible service vehicle for performing in-space operations on a target spacecraft.
20 Furthermore, a servicing system and a method for in-space servicing of spacecraft shall
21 be provided.

22
23 With respect to the service vehicle, this object is achieved with a communication module
24 which with respect to its transmission characteristics is configurable in order to meet gi-
25 ven receiver parameters of said selected target spacecraft.

26
27 The services provided by the service vehicle may include any types of services, such as
28 refueling, delivering all kinds of material, repair or maintenance services, or other kinds of
29 suitable activities. Said services may collectively be denoted as ACR for Assembly, Con-
30 vert and Repair. The majority of said ACR services are to be performed by means of te-
31 leoperation assisted by stereoscopic means, illuminating means & tape-tools that assist in
32 fetching/storing tools and fetching/storing spares and fetching/storing disassembled com-
33 ponents.

1 The invention is based upon the concept that for flexible and versatile servicing of a target
 2 spacecraft, the service vehicle ought to be designed for a particularly low mass, energy
 3 and/or fuel budget. However, a significant contribution to both mass and energy/fuel re-
 4 quirements is the necessity to constantly provide for reliable communication between the
 5 service vehicle and a ground control station, in particular in view of the comparatively lar-
 6 ge distances that must be overcome between ground control and service vehicles in ex-
 7 pected servicing missions. In order to significantly lower the onboard power consumption
 8 on the service vehicle necessary for maintaining a reliable communication channel with
 9 ground control, the service vehicle is designed for emitting signals to ground control by
 10 using the target spacecraft to be serviced as a relay station. In this concept, the energy
 11 required from the service vehicle may be limited to maintain a communication channel
 12 with the target spacecraft, and accordingly the mass required to provide these lowered
 13 energy levels – i. e. accumulator mass – may be kept correspondingly low. The major
 14 share of the energy necessary to maintain proper communication in this concept is then
 15 delivered by the target spacecraft which as such is designed for communicating with
 16 ground control anyway. In order to render the target spacecraft useable for this purpose,
 17 the service vehicle is designed to be configurable to establish communication contact with
 18 the target spacecraft.

19
 20 Particularly advantageous features of the present invention are specified in the dependent
 21 claims.

22
 23 In a preferred embodiment, the service vehicle is designed with particular emphasis on
 24 the concept to keep the target spacecraft safe from over-extensive or potentially destruc-
 25 tive energy input from the service vehicle while also providing for a comparatively high
 26 range of distances to the targeted spacecraft over which reliable communication may be
 27 established. In order to achieve these accumulated goals, which with respect to the output
 28 power emitted by the service vehicle contradict each other, the service vehicle preferably
 29 is designed for variable output power of its communication module. For this purpose, the
 30 service vehicle preferably is equipped with a control module for providing a setpoint for
 31 an output power of said configurable communication module. In further preferred embo-
 32 diments, the setpoint for the output power is chosen in dependence of the current distan-
 33 ce between service vehicle and target spacecraft and/or the relative orientation of the
 34 target spacecraft with respect to the service vehicle. Accordingly, the control module pre-
 35 ferably inputwise is connected to a first position sensor, said first position sensor deli-

1 vering a set of data characteristic for the current position of said service vehicle, to a se-
2 cond position sensor, said second position sensor delivering a set of data characteristic
3 for the current position of said target spacecraft, and/or to an orientation sensor, said ori-
4 entation sensor delivering a set of data characteristic for the current orientation of said
5 target spacecraft in relation to said service vehicle.

6
7 In a particularly advantageous embodiment, which may also be used independently from
8 the communication concept as identified, the service vehicle is designed for reliable and
9 easy-to-use docking at the target spacecraft. For this purpose, it preferably comprises a
10 docking system, said docking system comprising a hollow first axle inside of which a se-
11 cond axle is moveably disposed, said second axle carrying an activateable arrow tip. For
12 docking purposes, the activateable arrow tip may be inserted into the exhaust system of
13 the thrusters of the target spacecraft via the axle system. Once inserted into the interior of
14 the exhaust system, the arrow tip, preferably a double-arrow tip, may be activated in order
15 spread the arrow fingers apart. Retracting the arrow tip via the axle system will then cau-
16 se the arrow tip to engage with the side walls of the engine exhaust, thus providing for
17 reliable docking at the target spacecraft.

18
19 With respect to the servicing system, the object identified above is achieved with a ser-
20 vice vehicle as described above, further supplemented by a ground control unit for deli-
21 vering operational commands to the service vehicle. In order to consequently use the tar-
22 get spacecraft for relaying communication signals from the service vehicle to ground con-
23 trol in this servicing system, the ground control unit preferably is set up to receive data
24 from the service vehicle by using the target spacecraft as a relay station for signals emit-
25 ted from the service vehicle.

26
27 The servicing system may further be supplemented by an orbit-based service base for the
28 service vehicle and/or by a propulsion module attachable to said service vehicle.

29
30 With respect to the method for in-space servicing of a selected target spacecraft, the ob-
31 ject identified above is achieved in that a service vehicle as identified is used to perform
32 selected in-space operations on the target spacecraft, whereby operational signals from
33 the service vehicle are transmitted to a ground control unit by using the target spacecraft
34 as a relay station for the operational signals.

Among others, the main advantages of the present invention are that particularly inexpensive apparatus and methods for performing particularly inexpensive science missions from space, requiring consumables or/and robotic facilities, are provided. Furthermore, particularly inexpensive apparatus and methods for altering orbits of passive or active objects in space for whatever reason (anti-collision, operational) or maintaining its position against perturbing forces are provided as well as inexpensive apparatus and methods for effecting reconfiguration, maintenance and/or assembly operations. Still furthermore, the invention pertains to reusable synergetic apparatus and methods for performing inexpensively a variety of proximity operations, e.g., inspection of an operational or -non-operational satellite, to determine its status, (its weight, its temperature profile, the operation or its subsystems), and/or to reusable synergetic apparatus and methods for inexpensively delivering or replenishing supplies to orbiting spacecraft or complexes such as the international space station.

Furthermore, to ground or elsewhere a high bandwidth telecommunication link originating from a simple inexpensive low powered servicing module is provided, optionally together with a simple method of controlling a spacecraft through part of the telemetry produced by another spacecraft, and/or an inexpensive apparatus and method for recovering telemetry information from a spacecraft whose telemetry means transmit at very low power. Still furthermore, the invention provides apparatus and method for recovering telemetry information from a spacecraft whose telemetry means transmit in very low power and encrypt it before retransmission through on-board means or through means of the serviced spacecraft, and/or an inexpensive simplified mechanical grip for capturing a satellite from the interior of the combustion chamber of the satellite and method of securing the grip, resulting to a pair of bodies (satellite & service module) of high stability.

An in-space service vehicle, in order to provide even the minimum of services, namely inspection, it requires to be equipped with one or more cameras and means to establish an associated High Bandwidth Communication Link (HBCL) to the ground. Through this link it provides in real-time, the visual or infrared or other high bandwidth information that is captured, to teleoperators at the ground, to enable teleoperation. The said link requires very demanding resources (power, telecommunication means), especially if the service is to be offered at the geostationary ring level.

1 The method in accordance with the invention includes usage of telecommunication means
2 of said satellit for the transmission of the said images to teleoperating controllers at the
3 ground segment and not effecting as usually has been proposed, the link directly to the
4 Ground Stations in an autonomous manner. The service vehicle proposed possesses
5 means for transmitting at low power and at the frequency of an operational up-link trans-
6 ponder of the target spacecraft 2 the video signal properly modulated. The satellite shall
7 retransmit as normally the respective converted and amplified signal through the respecti-
8 ve down-link transponder. Preferably, the up-link transponder of the operational trans-
9 ponder chosen for the said link shall cease operation during the service mission to allow
10 unhindered image reception to the Ground Segment.

11
12 An exemplary embodiment of the present invention is explained in greater detail with refe-
13 rence to the drawings in which:

14
15 Fig. 1 shows a first version of a servicing system for providing in-space service operations
16 to a selected target spacecraft,

17
18 Fig. 2 shows a second version of a servicing system for providing in-space service opera-
19 tions to a selected target spacecraft,

20
21 Fig. 3 shows a service vehicle of the servicing system according to Fig. 1 or Fig. 2 docked
22 to the target spacecraft,

23
24 Fig. 4 shows a schematic structure of the communication system of the service vehicle
according to Fig. 3,

25
26 Fig. 5 shows a utility base of the servicing system according to Fig. 1 or Fig. 2,

27
28 Figs. 6a, b show a flexible storage module of the utility base according to Fig. 5 in inflated
29 (Fig. 6a) and deflated (Fig. 6b) condition, respectively,

30
31 Fig. 7 shows a schematic view of the internal layout of an equipment and storage bay of
32 the utility base according to Fig. 5,
33

Figs. 8a-c show a robotic manipulator for use in the interior of the equipment and storage bay according to Fig. 7 in side view (Fig. 8a) and in top view (Fig. 8b) and a cross section of a rail system for the robotic manipulator (Fig. 8c),

Fig. 9 shows a docking and refueling rack of the utility base according to Fig. 5,

Figs. 10 a, b show a side panel (Fig. 10a) and a top panel (Fig. 10b) of the docking and refueling rack according to Fig. 9,

Fig. 11 shows a catch system, particularly for use in the utility base according to Fig. 5, and

Fig. 12 shows an action tip for the catch system according to Fig. 11.

In all figures, identical parts are provided with identical reference numerals.

Following terms as used herein mean:

Spacecraft: is any type of manmade apparatus that is launched in space as a whole or produced through assembly in space.

Satellite: is a spacecraft that has entered a roughly determined orbit around a celestial body (planet, natural satellite or sun). "Orbital elements" are called the set of parameters that are describing this orbit.

Delta velocity: is the velocity increment or decrease of a spacecraft with respect to its vector of motion, by the application of a force that is called trust and is provided through the thrusters of the spacecraft.

Total delta velocity potential: is the cumulative sum of the delta velocity a spacecraft can generate throughout its operational life.

Geostationary object: is an object that has an eastwards circular orbit around earth at a height of about 35,786.4 KM above the sea level. Characteristic of tremendous significance of this orbit is the fact that the object rotates with the same angular velocity as the

1 earth and so it is visible as stable above the equator at certain Longitude, making possi-
2 ble the continuous communication with it through a single stably pointing antenna. The
3 sub-satellite point is stable and is located at a certain longitude at the equator.

4
5 Station keeping maneuvers: are these maneuvers that are required to put or return a
6 spacecraft to its desired point (or trajectory for missions with no stable sub-satellite point
7 eg Molniya) of operation.

8
9 Fail-Safe: a technical characteristic of an apparatus that is designed in such a way that
10 when it fails for any reason it does not pose a risk apart from the loss of service it is de-
11 signed to offer.

12
13 The servicing system 1 according to Figs. 1 and 2 is designed to provide in-space service
14 operations to a selected target spacecraft 2, in particular a target satellite, at both high
15 reliability levels and low fuel/cost levels. In this context, the servicing system is designed to
16 provide the services both to so-called cooperative (or controllable) targets as is shown in
17 Fig. 1, or to non cooperative (or non controllable) targets as is shown in Fig. 2.

18
19 In order to provide services in a broad variety of missions, typically in each mission type
20 units of several, in particular three, species are used. These various species of space-
21 craft, in various numbers depending upon mission, co-operate in a synergetic manner in
22 order to provide a service to the target spacecraft 2, either cooperative or non-
23 cooperative.

24
25 As a first element, the servicing system 1 comprises a module serving as a utility base 4,
26 in the role of mothership for further elements. The second element, a service vehicle 6,
27 has the role of the actual service provider to the target spacecraft 2 and may also be re-
28 ferred to as a "Utility Agent service vehicle 6". A third element is an engine module 8, po-
29 tentially a subset of the service vehicle 6, suitable for permanent orbit maintenance ser-
30 vice on a cooperative target. As fourth element, a specialized vehicle 10 for missions with
31 non-co-operative targets, or for carrying and operating specialized repairing means or
32 communication relay means, also referred to as "Escort Agent EA" may be provided.

33
34 By use of the servicing system 1, the existing fleet of spacecraft can be adequately ser-
35 viced and upgraded, and future spacecraft can be produced at much lower cost, much

1 lower mass and much shorter time, making use of the advanced repairing and upgrading
2 capabilities of the service fleet of the servicing system 1. Operational life of spacecraft is
3 extended, capabilities are augmented, space debris problem is mitigated. In this context,
4 the service vehicle 2 is designed to provide a series of operations dissimilar in nature and
5 complexity. In general, a single service vehicle that would embody all potential characteri-
6 stics would be too expensive to construct, as many studies have shown. Furthermore, its
7 size and weight would increase the risk and operational cost. Taking into account the po-
8 tentially large variety of mission types and that it would require to perform high and often
9 changes in velocity any saving in weight budget would pay back many times.

10
11 Therefore, the service vehicle 6 is designed for particular weight-effectiveness and flexibi-
12 lity. This primary goal is achieved by the fundamental design philosophy that it is specially
13 designed to be teleoperated through a high bandwidth link via the target spacecraft 2 it-
14 self. On that respect it remains autonomous from the utility base 4 for long although small
15 and it gains reusability potential by the means of the utility base 4. Accordingly, in order to
16 allow for low energy consumption and the corresponding savings in weight (i. e. for ener-
17 gy storage devices such as batteries), the service vehicle 6 is designed to communicate
18 with a ground control module 12 via a relay station. In the operating mode as shown in
19 Fig. 1, the target spacecraft 2 itself is used for relay purposes. As indicated by the arrows
20 14, 16, signals emitted by the service vehicle 6 are transmitted to the target spacecraft 2,
21 thus according to close proximity demanding only limited transmission power. The service
22 vehicle 6 emits the signals to the target spacecraft 2 in such a way that the target space-
23 craft 2 is operated to forward the signals to the ground control module 12, for this purpose
24 providing the required (comparatively high) transmission power from its onboard energy
25 sources.

26
27 In case a non-cooperative target spacecraft 2 is to be serviced, as is shown in Fig. 2, the
28 service vehicle 6 may be accompanied by a specialized vehicle 10 in this context provi-
29 ding the necessary transmission power.

30
31 In order to facilitate using the target spacecraft 2 for the intended relaying purposes, the
32 service vehicle 6 is equipped with a communication module that can be configured such
33 that it can communicate with an arbitrary target spacecraft 2 in order to command it to
34 forward incoming signals to ground control module 12.

1 The service vehicle 6 is shown in more detail in a position docked to the target spacecraft
2 2 in Fig. 3. Within an outer main body 20, a plurality of servicing facilities (not shown in
3 detail, but selected appropriately to provide the service required) is disposed. Attached to
4 the main body 20, there is a separable propulsion system 22 mainly based on the use of
5 conventional thrusters. In order to firmly attach itself to the target spacecraft 2 after the
6 final approach, the service vehicle is equipped with a docking system 24 designed to en-
7 gage with the exhaust system 25 of the target spacecraft 2. In order to provide visual in-
8 formation for final approach, or to inspect the target spacecraft 2, a number of cameras
9 26 is attached to the main body 20.

10
11 The service vehicle 6 is equipped with a built-in communication system 28, which datawi-
12 se is connected to an altitude and orbit control system 30 of the service vehicle 6. The
13 communication system 28 is designed to, at close enough distances, establish a commu-
14 nication channel with the so-called up-link communication channel of the target spacecraft
15 2. For this purpose, as indicated by the dashed line 32, the communication system 28
16 establishes a communication channel with a receiver 34 of the up-link channel of the tar-
17 get spacecraft 2. Via this communication channel, the communication system 28 trans-
18 mits commands or signals at a comparatively low output level that within the target
19 spacecraft 2 are relayed and forwarded to the emitter 36 of the so-called down-link chan-
20 nel of the target spacecraft 2. As indicated by the arrow 38, the signals are then forwar-
21 ded via the down-link channel to the ground control module 12 at a comparatively high
22 transmission power, the energy for which is derived from the on-board energy sources of
23 the target spacecraft 2.

24 For easier maneuvering relative to the target spacecraft 2, the service vehicle 6 is equip-
25 ped with a laser unit 39 set up to identify the distance of the service vehicle 6 from the
26 target spacecraft 2.

27
28 The docking system 24 of the service vehicle 6 mainly comprises a hollow axle 40, an
29 activation axle 42 inside the hollow axle driven by a fail-safe mechanism 44 that allows
30 extension, retracting or rotation of the hollow axle. At the free end of the activation axle
31 42, a double arrow opening tip 46 (one arrow being smaller than the other) is provided.
32 The double arrow opening tip 46 is opening by means of retracting the activation axle 42
33 and an even surface around the activation axle 42 to permit even contact of the front
34 surface 48 of the service vehicle 6 with the nozzle ring 50 of the exhaust channel 52 of
35 the target spacecraft 2, providing high stability when engaged.

1
2 The method of docking consists of the following phases: alignment of axle 40 to nozzle
3 50, entering the activation axle 42 into combustion chamber 54 of the target spacecraft 2,
4 opening of the arrowheads, rotation if needed with stepwise retracting, final retracting of
5 hollow axle 40 and fail-safe engaging of the double arrow opening tip 46 with the interior
6 of the combustion chamber 54.

7
8 At approaching the target spacecraft 2, the arrow head sides shall be aligned parallel to
9 the axle 40. The axle 40 is guided towards the center of the combustion chamber 54
10 through the nozzle 50 and when it passes the neck of the chamber 54 the arrow head
11 sides are opened wide to the maximum, through retracting the activation axle 42 in order
12 to secure it inside the combustion chamber 54. If the angular alignment between service
13 vehicle 6 and target spacecraft 2 is satisfactory then the securing and safeing phase is
14 started, if not then the mechanism 44 retracts the hollow axle 40 and rotates the activa-
15 tion axle 42 in successive steps until the desired angular alignment is achieved. Then the
16 retreating mechanism 44 retreats slowly and firmly the hollow axle 40 until the surface of
17 the service vehicle 6 reaches and presses onto the nozzle end-ring of the target space-
18 craft 2. The activation axle 42 is fail-safe secured at this position and is released only by
19 command or if a general failure occurs. In case of a power failure or mechanical failure or
20 processing failure the activation axle 42 is left to its natural position by means of a spring
21 that forces the arrowheads close. An independently powered timer controls the safeing
22 mechanism. As long as the anomaly detection mechanism has detected no anomaly
23 threatening the target spacecraft 2, the activation axle 42 pushes open the arrowheads. In
24 the case a threatening anomaly is detected the activation axle 42 is left free and, forced
25 by a spring, lets the arrowheads close. Any forward movement of the target spacecraft 2
26 lets the service vehicle 6 to free float in space.

27
28 The structure of the communication system 28 of the service vehicle 6 is shown schema-
29 tically in Fig. 4. As a key component, the communication system comprises a communi-
30 cation module 60 which is designed such that with respect to its transmission characteri-
31 stics it may be configured in order to meet given receiver parameters of the selected tar-
32 get spacecraft 2. Accordingly, by proper configuration of the communication module 60,
33 communication with any kind of target spacecraft 2 may be established and hence the
34 service vehicle 6 can be teleoperated by using the target spacecraft 2 for relaying signals.
35

1 The communication module 60 comprises a multiplexer 62, connected to a signal modu-
2 lator 64. Multiplexer 62 together with modulator 64 generate the signals to be transmitted.
3 For transmission purposes, the communication module 60 further comprises a transmitter
4 66 in connection with the modulator 64. For configurability, the transmitter 66 is equipped
5 with a controller module 68, which if supplied with the required data format may reconfigu-
6 re the transmission characteristics of the transmitter 66 on a software basis. Furthermore,
7 within the communication module 60, the transmitter 66 is exchangeable. Accordingly,
8 configuration of the communication module 60 may also be carried out in a hardware
9 manner by providing an alternative transmitter 66. Since there are a plurality of satellite
10 types or categories, preferable configuration is carried out on a hardware basis, i. e. by
11 replacing the transmitter 66, if reconfiguration between different target spacecraft catego-
12 ries is desired, whereas reconfiguration is done on a software basis, i. e. by reprogram-
13 ming the controller module 68, if reconfiguration between different individual target
14 spacecraft of the same category is desired.

15
16 Inputwise, the multiplexer 62 is connected to an encoder 70, which in turn receives its
17 input data from a camera 72 and/or a proximity sensor 74. Furthermore, the multiplexer
18 62 inputwise is also connected to a telemetry system as indicated by the arrow 76.

19
20 With respect to its output power, the transmitter 66 is adjustable in order to make sure
21 that the power emitted will not endanger or destroy the target spacecraft 2 due to close
22 proximity. Accordingly, the transmitter 66 is equipped with a control module 78 designed
23 to provide an appropriate setpoint for the output power. The control module preferably
24 generates the setpoint for the output power based upon a signal strength received from
25 the target spacecraft 2, which is characteristic for the relative distance of the service ve-
26 hicle 6 from the target spacecraft 2. Accordingly, inputwise the control module 78 is con-
27 nected to a communication receiver 80 of the communication system 28. The receiver 80,
28 which inputwise receives signals from the target spacecraft 2 as indicated by the arrow
29 82, outputwise is connected to general data handling of the service vehicle 6 via a demo-
30 dulator 84. Further components, such as a docking subsystem 86, the proximity sensor
31 74 directly via a branch line 88, retroreflectors 90 mainly used for other spacecraft to dock
32 on, or an optional refueling module 92 are also connected to a telecomand bus or general
33 data handling of the service vehicle 6.

1 Beyond, the functional composition of the bus system of the service vehicle 6 comprises
2 the following subsystems: a structure subsystem, the data handling subsystem (DHSS),
3 an electric power subsystem (EPS), a thermal control subsystem (Ttarget spacecraft 2),
4 an attitude orbit & control subsystem (AOtarget spacecraft 2), a telemetry tracking &
5 control subsystem (TT&C), and a propulsion subsystem (PSS), characterized by no re-
6 dundancy in any of the subsystems budgets.

7
8 Albeit the fact that these subsystems are present in the majority of spacecrafts the bus of
9 the service vehicle 6 is characterized by low capability budgets of the respective subsys-
10 tems, in account of its mission and the lack of redundancy. The lack of redundancy is
11 justified by the capability, in case of failure of a given fleet unit, of recovering it through
12 another service vehicle 6 or specialized vehicle 10 and subsequently repairing it at the
utility base 4.

14
15 In particular, the EPS consists of small solar cell array panels (SAP) capable to produce
16 part of the energy required during missions. Start of mission charging is performed at the
17 utility base 4 before the mission starts. Likewise, the batteries of the service vehicle 6 are
18 undersized, as at proximity to the utility base 4 the telemetry is relayed through the utility
19 base 4, at cruise if needed directly to earth and then at approach of the target spacecraft
20 2 through the target spacecraft 2. At proximity to the target spacecraft 2, the target
21 spacecraft 2 is used as relay for both the TT&C and the cameras output. The EPS does
22 not cater for any high-bandwidth link to support teleoperation or robotic facility or both as
23 it is usually being proposed. Considering that the EPS of a typical spacecraft is 30% of its
24 mass budget this saving is of high importance.

26 The TT&C transmitter is of low bit-rate and characterized by the use of Adaptive Power
27 Control APC. The TT&C transponders can be switched off when in proximity to the target
28 spacecraft 2. In this case the telemetry TM and telecommand TC are transferred through
29 the payload.

30
31 The service vehicle 6 to perform docking and operations establishes one forward link
32 with the teleoperators, preferably at ground control module 12, and a return link both
33 through the target spacecraft 2.
34

1 The forward link is established as follows: The encoder 70 of the service vehicle 6 pay-
2 load receives two inputs, one for the signal of the camera 72 and one for the proximity
3 sensor 74 and generates two encoded signals for the camera signal and the proximity
4 sensor respectively. The multiplexer 62 receives these two signals plus the encoded TM
5 signal from the DHSS of the bus and multiplexes the three, producing a composite signal.
6 The modulator 64 receives the composite signal, produces a modulated signal and feeds
7 the transmitter 66 which amplifies and transmits the signal that is fed to the up-link re-
8 ceiver of a channel of the target spacecraft 2. The target spacecraft 2 receives the signal
9 and transmits to the ground. The transmitted signal arrives through the ground control
10 module 12 at a Mission Control Centre (MCC) for analysis and informed action.

11
12 The teleoperators in the MCC generate telecommands for the service vehicle 6, which are
13 embedded within the telecommands for the target spacecraft 2. These telecommands for
14 the service vehicle 6 are flagged with the request only to echo them and not to be exe-
15 cuted by the target spacecraft 2. Following the reception of the telecommands the target
16 spacecraft 2 echoes them from the telemetry channel. This signal is easily intercepted by
17 telemetry receiver of the service vehicle 6.

18
19 The telecommand reception is established as follows: The telemetry listen-in receiver
20 receives the totality of the telemetry of the target spacecraft 2 and produces a signal that
21 forwards for demodulation at the demodulator 84. After demodulation the resulting signal
22 is forwarded to the DHSS of the bus and in particular at the application software where
23 the analysis of telemetry is performed for extracting this information that consists com-
24 mands to the service vehicle 6.

25
26 The main types of operation of the service vehicle 6 in relation with a mission are cruising
27 from the utility base 4 which is serving as a starting platform for each mission, approach-
28 ing the target spacecraft 2 (rendezvous and teleoperation), return from the target space-
29 craft 2 to the utility base 4, and resting at the utility base 4 until the next mission for the
30 respective service vehicle 6 is started.

31
32 When cruising from the utility base 4 to the target spacecraft 2 ("Cruise mode"), the serv-
33 ice vehicle 6 travels from the utility base 4 to the target spacecraft 2 alone and autono-
34 mously making use of the star tracker. The power output of the TT&C of the bus is ad-
35 justed so that telemetry link can be established by the bus TT&C through either the utility

1 base 4 or the target spacecraft 2. If neither is possible due to large distances, the service
2 vehicle 6 may be escorted in the needed part of its cruise by a specialized vehicle 10,
3 may be used to relay telemetry and telecommands from a ground control module 12 to
4 the service vehicle 6 and vice-versa, thus rendering the service vehicle 6 operable in any
5 state of the cruise in spite of its limited on-board transmission and fuel capacities.

6
7 For rendezvous and teleoperation, during the coast phase from the utility base 4 to the
8 proximity of the target spacecraft 2 the star images from the cameras 26 are used for
9 autonomous navigation. During the approach and rendezvous phases the service vehicle
10 6 is controlled by means of open loop successive command cycles until docking is se-
11 cured.

12
13 At each command cycle the real-time output of the cameras 26 is encoded, multiplexed,
14 and modulated together with telemetry information of the service vehicle 6 (and optionally
15 with the output of the proximity sensor 74). The resulting signal is transmitted by the low
16 power transmitter 66 to an up-link channel of the target spacecraft 2 through its up-link
17 antenna. The target spacecraft 2 retransmits through the respective down link channel
18 said signal to the ground control module 12 which may be part of a ground station (GS)
19 and mission control center (MCC). The receiver of the ground control unit 12 receives the
20 composite signal, demodulates and de-multiplexes and then decodes the image, teleme-
21 try and proximity sensor signals and forwards them to the MCC. The telemetry informa-
22 tion and proximity sensor information is recorded at the MCC, analyzed and several de-
23 rivative parameters are generated to optimize motion commands of the teleoperation ap-
24 paratus. Said optimization compensates for fuel mass changes, sloshing activity, thruster
25 efficiency, fuel temperature, combustion chamber temperature and other biasing factors
26 difficult to be handled by an operator in real time. The real-time image together with the
27 summary proximity information and other rendezvous related information (relative angles,
28 time windows of critical steps, fuel reserves etc) is displayed onto virtual-reality head-on
29 display systems of a plurality of teleoperators.

30
31 Said teleoperators have control over actuators generating appropriate commands which
32 pass through the above said optimization. Said optimized telecommands are packed in
33 special telecommands of the target spacecraft 2 and are forwarded from the MCC to the
34 transmitting part of the ground control module 12, encoded, modulated and transmitted as
35 part of the telecommand stream to the target spacecraft 2 with appropriate identification.

1 The telecommands that are addressed to the service vehicle 6 are echoed by the down
2 link (telemetry) of the TT&C of the target spacecraft 2 and listened-in by the TT&C re-
3 ceiver of the service vehicle 6. The listened-in telemetry signal is demodulated and de-
4 coded and a telecommand selector parses the telemetry and selects telecommands ad-
5 dressed to the service vehicle 6. The said telecommands are executed and telemetry is
6 generated that in turn is encoded, multiplexed with the outputs of the cameras 26 and
7 proximity sensor 74, modulated and then transmitted to the selected up-link channel of
8 the target spacecraft 2.

9
10 This command cycle is repeated until the docking system 24 is securely fastened inside
11 the combustion chamber 54 of the target spacecraft 2.

12
13 Upon mission completion or fuel shortage, the service vehicle 6 returns to the utility base
14 4 for resting or refueling, respectively.

15
16 In proximity to the utility base 4, maneuvering of the service vehicle 6 is assisted by the
17 surveillance means of the utility base 4. The service vehicle 6 assisted by the utility base
18 4 sensors and retroreflectors performs preferably an automatic docking at the utility base
19 4. However, teleoperated docking may also be performed.

20
21 In the "resting mode", under service-call wait-status, the service vehicle 6 rests, preferably
22 at the utility base 4, preferably in a storage mode that consumes very limited resources. It
23 is envisaged that, at full deployment, there will be provided a multitude of service vehicles
24 6 at a single utility base 4 with some variations in size and interfaces to correspond to
25 specific types or categories of target spacecraft 2, or to better a match a selected type or
26 level of service to be provided to the target spacecraft 2.

27
28 In case that the target spacecraft 2 requires specific services from subsystems of the util-
29 ity base 4 (robotic facility, ...), the service vehicle 6 may be operated to fetch the target
30 spacecraft 2 to the utility base 4 for servicing and places back to the desired post after
31 service ("porting mode").

32
33 The service vehicle 6 depending of the mission duration may be equipped with additional
34 fuel reserves and a fuel delivery subsystem. In another variation, the service vehicle 6
35 may be designed to perform a variety of missions with add-on accessories. For example,

1 a service vehicle 6 equipped with drilling means and endoscope may be used in tandem
2 with a specialized vehicle 10 for performing indepth investigations of failure causes or
3 other rescue missions.

4
5 The engine module 8 of the service vehicle 6 primarily is used for orbit maintenance of a
6 target spacecraft 2 and for potentially reserving fuel of a target spacecraft 2. The engine
7 module 8 comprises a subset of elements of the service vehicle 6. In particular, the bus of
8 the engine module 8 may be part of the attitude and orbit control subsystem if the mission
9 is propulsion only. Its payload consists of a fail-safe docking-securing mechanism identi-
10 cal with the one of the service vehicle 6 and a TT&C that interfaces with the TT&C of the
11 target spacecraft 2 in a way similar to the concept of the service vehicle 6. This TT&C
12 comprises a telemetry listen-in receiver-demodulator-decoder-command selector and an
13 encoder-modulator-transmitter that transmits to the up-link of the TT&C channel or other
14 channel, as preferably of the target spacecraft 2.

15
16 The engine module 8 possesses electrical and data interfaces for mating with a porting
17 service vehicle 6, and optionally a fuel reception inlet. It disposes at all sides retroreflec-
18 tors that facilitate automatic docking of a visiting or refueling service vehicle 6. The engine
19 module 8 may be used to be forwarded and attached to a target spacecraft 2 by means of
20 a service vehicle 6. When mission fuel depletes it receives additional fuel by a refueling
21 service vehicle 6. Return to the utility base 4 may then require a porting service vehicle 6.
22 In case of critical failure the fail-safe mechanism is automatically released.

23
24 The level of redundancy of the engine module 8 is customizable according to mission
25 requests. An engine module 8 for a target spacecraft 2 with no fuel reserves preferably
26 has full redundancy. An engine module 8 for a target spacecraft 2 with fuel sufficient for a
27 few months operation may be designed with no redundancy.

28
29 At full-scale deployment of the servicing system 1, a plurality of utility bases 4 may be
30 held available. The most preferable position to start with is the geostationary ring, less
31 preferable the low earth sunsynchronous polar orbit. Any other possible orbital plane is
32 object for positioning a utility base 4 but markets other than that of the geostationary ring
33 and the sunsynchronous polar orbits need still to be matured.

1 The utility base 4, which is shown in Figure 5 in more detail, represents the mother ship
2 for service vehicles 6 or other vehicles 10 of the servicing system 1. As main components,
3 the utility base 4 comprises a main body 100, which primarily houses control systems and
4 the like and contains the bus system of the utility base 4, an equipment/storage bay 102,
5 a docking/refueling rack 104, and a flexible storage module 106. The interfaces between
6 these segments dispose power, data "TMTC" and plurality of video signal connectors.

7
8 Attached to the main body 100, primary solar panels 108 are provided for energy supply.
9 For redundancy purposes, secondary solar panels 110 are attached to the equip-
10 ment/storage bay 102. The equipment/storage bay 102 further carries a support grid 112
11 for securing and storing items if needed. In order to potentially move items around, a ro-
12 botic arm 114 preferably extending beyond the support grid 112 is mounted onto the main
13 body 100. For establishing communication channels, a number of reflectors 116 of anten-
14 na are attached to the equipment/storage bay 102. The primary and redundant large
15 aperture parabolic antennas are mounted onto the down-out side of the equip-
16 ment/storage bay 102.

17
18 In order to allow for docking of a multitude of service vehicles 6 or specialized vehicles 10,
19 especially for resting purposes without the need for supplying the respective vehicle
20 further, the utility base 4 is equipped with a number of docking stations 118. Although in
21 Fig. 5 only one docking station 118 is explicitly identified, further docking stations (pre-
22 ferably at least four in total) are provided, preferably at least one in every main direction of
23 the utility base 4.

24
25 In general, the utility base 4 is characterized by a "hot redundant" architecture protecting
26 against two points of failure of all its vital functions (links to the ground, robotic functions,
27 docking spaces) and mechanisms (e. g. electric power subsystem, attitude control sub-
28 system), providing survivability of itself and of the carrying fleet against double failures.

29
30 The utility base 4 comprises means of active and passive surveillance of the surrounding
31 space (ranging lasers, radar systems) and has active means (potentially reying on docked
32 or otherwise available service vehicles 6) for avoiding collisions with other elements in
33 open space (ablating laser). Given the replenishment capability of its resources through
34 often replenishment missions and the high redundancy of is vital functions, the utility base

1 4 that is placed at the geostationary ring may in essence be the first space platform with
2 indeterminable life span.

3
4 It is used to perform surveillance, protection, positioning, hosting, storing, reconfiguring,
5 repairing, converting, assembling, and science missions.

6
7 Assuming the position of the utility base 4 at the Geostationary ring at mid day, a coordi-
8 nate system passing from the geometric centre of its central segment is defined as fol-
9 lows. X axis has west to east direction, Y axis has Earth to Sun direction and the Z axis
10 has South to North direction. For the X axis also the left-right notion is used where X in-
11 creases to the left, for the Y axis the near-far notions are used where Y increases towards
12 far, and for the Z axis Up an-Down notions are used where Z increases towards up direc-
13 tion. When relative reference of a segment of the utility base 4 other than the central one
14 is made, in relation to the centre of the utility base 4, the terms IN-side and OUT-side are
15 also used. In-side denotes the side close to the centre and out-side meaning the side of
16 the segment at question which is opposite to the In-side at a direction departing from the
17 centre.

18
19 The bus system of the utility base 4 mainly consists of a double redundant TT&C sub-
20 system, a redundant attitude and orbit control subsystem (AOCS), a redundant electric
21 power subsystem (EPS), a redundant data handling subsystem, and a redundant thermal
22 control subsystem (TCS). All subsystems are characterized by hot redundancy. The utility
23 base 4 receives power primarily from the solar panels 108 (preferably three or more)
24 mounted onto booms connected to an axial truss through mechanisms having three de-
25 grees of freedom. The truss is characterized by passing from the geometric and momen-
26 tum center of the main body 100 through the same axis as the robotic arm 114. The ac-
27 tuators of the solar panel mounting mechanisms of the primary and redundant solar pan-
28 els 108, 110 are part of the AOCS.

29
30 The robotic arm 114 is designed to have five degrees of freedom (DOF) for the actual
31 arm 120 and three degrees of freedom for its wrist element 122. The robotic arm 114 is
32 dimensioned such that it can reach all upper, side and under areas of the utility base 4
33 that may need servicing.

1 The communication system or payload of the main body 100 also possesses a redundant
2 near range mission communication system, preferably for ten-channel RF video reception
3 equipment, a video switch system, and a redundant communication payload, for trans-
4 mission to the ground of four uncompressed and twelve compressed digital video signals,
5 generated by the various surveillance and teleoperation cameras. The redundancy of the
6 mission communication system to the ground may provided by a specialized vehicle 10
7 docking at the far end of the equipment/storage bay 102.

8
9 The utility base 4 does not necessarily possess its own propulsion system, but fleet units
10 (service vehicles 6/specialized vehicles 10) may be attached to the four sides and com-
11 manded appropriately when needed for orbit maintenance. Attitude stability of the utility
12 base 4 is achieved, in short time, by use of the steering mechanisms of the solar panels
108,110. The utility base 4 is axi-symmetrically momentum stabilized.

14
15 The flexible storage module 106 mainly consists of a flexible, inflatable, lightweight bal-
16 loon-like surface sheet, the size and shape of which may be modified by retreating means
17 124. In the embodiment shown, the retreating means 124 mainly are provided by con-
18 tractable tapes which when contracted will diminish the volume of the interior of the mod-
19 ule 106 while increasing its volume when allowed to expand. Examples for the module
20 106 in expanded and in contracted status are shown in Figs. 6a and 6b, respectively. Ac-
21 cordingly, the flexible storage module 106 resembles a sack-shaped flexible storage bay
22 which possesses a plurality of ring shaped, tape-measure type tape-fastener, externally
23 secured to the sack by means of externally to the sack secured small elliptic fasteners.
24 Said ring tape is driven by a reel-unreel mechanism with dual reels having independent
25 motors. By reeling-in the tape the sack closes securing the free flying objects that are
26 placed in this sack and by unreeling the tape the sacks opens to let the robotic arm 114 or
27 other means collect the objects. Another tape fastened perpendicular to a securing ring
28 on the external surface of the sack elongates or shortens the sack respectively, increas-
29 ing or decreasing its volume.

30
31 The equipment/storage bay 102, the interior of which is schematically shown in Fig. 7,
32 and which also may be referred to as a closed equipment storage bay (CESB), is mainly
33 used for housing equipment and material sensitive to exposure to radiation, or tempera-
34 ture variations, or sun-rays, or small meteorites. It is where assembly, disassembly and
35 testing takes place for small mechanical, electromechanical or electronic subsystems.

1 The treatment of the material to be handled may or may not include packaging and un-
2 packaging in protective boxes.

3
4 The west side of the equipment/storage bay 102 disposes a pressurization controlled pro-
5 thalamus 130 with five outer doors 132 and a single internal door 134. The west door and
6 inner door 134 are disposed one opposite to the other in a way to allow long objects equal
7 to the long axis of the chamber to enter the bay in unpressurized conditions.

8
9 The equipment/storage bay 102 possesses conditioning means for effecting and control-
10 ling pressure, temperature and cleanliness by Nitrogen gas or other inert and non-volatile
11 gas. It possesses permanent camera viewpoints, equipment bay for manipulation of mi-
12 niature mechanisms and electronic circuit boards and components.

13
14 The up-side and down-side in the thalamus 130 for further description are defined with
15 respect to the position of the horizontal axis, up being the position where lighting sources
16 and gas in-jets are mounted, down being the position where gas outlets are mounted.

17 The gas jets are spread all along ceiling and gas outlets all along floor surface. The flow
18 of gas from up to down creates a small pressure potential to the free flying objects in a
19 way similar to gravity.

20
21 Manipulation of movable equipment within the equipment/storage bay 102 is performed
22 by means of a number of three-arm small-sized robots 140 slidably and rotatably moun-
23 ted on two horizontally secured axis 142. The long axis of the equipment/storage bay 102
24 defines the horizontal dimension. A third axis 144 with an H profile, the profile of which is
25 shown in Fig. 8c, is disposed in between the above two mentioned axis and disposes two
26 conductive surfaces 146 on its interior. Said conductive surfaces 146 are used by a the
27 robots 140 to slide along while at the same time supplying them with electric power.

28
29 As shown in Figs. 8a, 8b in greater detail, each robot 140 consists of a pair of two co-
30 operative human-like manipulation arms 148, each having six degrees of freedom, and a
31 third arm 150 of three degrees of freedom that is used for stability with a two finger grip-
32 per 152 designed to be engaged with the axis 144. Alternatively, for holding objects a
33 three-finger gripper may be provided. The arms 148 of the robots 140 have ten finger
34 grippers each. The robots 140 can be positioned in a face-to-face configuration for coope-
35 rative work. The human-like arms 148 of the robots 140 can be engaged to closed-chain

1 kinematic configuration for manipulation of objects. This means the one arm 148 follows
2 in tandem the movements of the other (driving) arm 148.

3
4 The robots 140 may be assisted by a plurality (minimum 2) of miniature (scale 1:3 of ro-
5 bots 140 or better) three arm robots 149 similar but without the sliding-rotation part of the
6 robots 140. Mobility is provided by a sliding mechanism perpendicular to the first element
7 of the stability arm. With small jumping movements, using the two or three arms, the ro-
8 bots 149 can always reach a horizontal axis, attach the sliding mechanism of the stability
9 arm and slide along. These robots 149 either work from an axis or reach working place by
10 a jump from the slide-on axis or are placed to workplaces by the robots 140. The robots
11 149 are secured, when in workplace, by means of using their stability arm (with 3 degrees
12 of freedom). Alternatively, they can be held by the holding arm of a robot 140 for common
13 manipulation of an object in parallel, assuming the object is secured in place by other
14 means. The robots 149 when in workplace are connected to power/data/video-output
15 interface and when in free float they use onboard power (batteries). Nevertheless, the
16 floating time is limited and the respective battery size accordingly. The robots 149 dispose
17 accelerometers and gyroscopic means for attitude control when in free floating conditions.

18
19 The equipment/storage bay 102 disposes its further elements mainly around at mid level
20 a bench surface, filled with holes for letting air pass through and create a small virtual
21 gravity effect, and a stiff edge for giving stability to the robots 140 when they grip on it.
22 Disposes also a plurality of grips for securing objects in place for manipulation. It further
23 disposes a table 154 for common, face to face manipulation with similar stiff edge, and a
24 plurality of storage racks 156 for storing/ affixing tools, accessories, and spares. The stiff
25 edge and other places at the racks 156 possess connectors for providing the robots 149
26 with power/data/video interface. The distance of the storage racks 156 allows the robots
27 149 to use the stability arm to attach itself to a rack 156 while the other might be engaged
28 to fetch/store activities. For moving from one rack 156 to another the robot 149 needs to
29 stabilize itself by using the human like arms, gripping a horizontal shelf or a number of
30 vertical bars, or a combination of a bar and a shelf, before disengaging the stability arm to
31 move to another shelf.

32
33 The common table 154 is surrounded by tool & parts affix area mainly for mechanical
34 works and a tool & parts affix area mainly for electrical & electronic works.

1 The docking/refueling rack 104, which in further detail is shown in Fig. 9, is designed to
2 be semiautonomous and usable for all types of fleet vehicles 10, service vehicles 6, and
3 the like. It is provided with standardized utility outlets 160 for power, data, video, fuel, oxi-
4 dizer and pressurization gas. At least two of the docking positions defined by the outlets
5 and their respective fixation means possess also relieve in-lets for emptying the supplies
6 of a fleet unit. Said inlets for fuel, pressurization gas, and oxidizer are disposed symmetri-
7 cally to the outlets, in respect to the docking unit centre. The docking/refueling rack 104
8 has a plurality of pairs of docking interfaces for the fuel, oxidizer and gas tanks 162 (min
9 two for each species), disposed at the upper and if needed also lower sides of the same.
10 Each fleet unit docking position has a pair of active securing mechanisms disposed sym-
11 metrically to the centre of same. The tank docking positions have each a three-point ac-
12 tive securing mechanisms. The schematics of these locking mechanisms are shown in
13 Figs. 10a, 10b, which display the side surface 166 (Fig. 10a) and the upper surface 168
14 (Fig. 10b) of the rack 104 with the other parts (esp. tanks 162) removed.

15
16 All fleet unit docking positions dispose retroreflectors for aiding approach and docking.
17 The centre of each fleet unit docking position is hollow to allow the grapple arm pass the
18 rack surface and secure the position by opening the arrowheads and retracting.

19
20 Distributed pairs of docking positions without fuelling outlets but with data and power out-
21 lets are disposed at all four sides of the utility base 4.

22
23 The docking/refueling rack 104 is semiautonomous in the sense that it possesses a lim-
24 ited power supply storage system, a thermal control subsystem and a data handling sub-
25 system that is designed for supporting docking, fuelling operations and conditioning inde-
26 pendently of the main body 100. The docking/refueling rack 104 can provide, through a
27 data interface, to the main body 100 of the utility base 4 all locally available data.

28
29 A further position on the docking/refueling rack 104 is reserved for a specialized vehicle
30 10 which can activate its cameras when needed, to survey the docking/refueling rack 104
31 and the rest of the utility base 4. The video signal of the cameras can become available to
32 the video switch of the main body either through a video interface or via RF transmission
33 to the RF reception payload of the main body 100. The docking/refueling rack 104 also
34 possesses a redundant pressure-up equipment for helium gas which is operated only
35 when connected through the interface to the main body 100. This capability of autono-

1 mous operation allows for the disconnection of the docking/refueling rack 104 from the
2 utility base 4 when deemed there is increased risk associated to performing hazardous
3 operations such as refueling. The docking/refueling rack 104 in this case is removed by
4 means of operating one or more fleet units and is returned back when hazardous opera-
5 tions have been completed.

6
7 The mechanical interface 170 that connects the dockin/refueling rack 104 to the main
8 body 100 disposes also connectors for the realization of connecting the various interfaces
9 of the docking/refueling rack 104 to the main body 100 (power, data, video).

10
11 Docking of other vehicles/objects is performed through customization of extension con-
12 structs. After a target spacecraft 2 or another floating object towed by fleet units is deliv-
13 ered to the robotic arm 114 for stabilization, stabilization grids are erected as required for
14 securing the object in place and release the robotic arm 114 for other activities. These
15 grids are constructed by means of a plurality of booms that are secured along the top of
16 the equipment/storage bay 102, by means of fasteners.

17
18 Furthermore, the utility base 4 may be equipped with an open storage bay (OSB). Said
19 bay is used to store equipment, tools, materials, products and spares that do not require
20 protection or conditioning, packaged or un-packaged. It may consist of two symmetric
21 racks, east and west, which are attached to the near side of the main body 100, through
22 respective mechanical, electrical, data, and video interfaces. Both racks (for redundancy
23 purposes) comprise interfaces for operating (command, data) an externally mounted de-
24 tachable parabolic antenna each, for communication with the fleet. In the case the stabili-
25 zation grid is deployed the redundant antenna is mounted onto the most western boom.
26 They also both, for redundancy purposes, dispose interface for power control and video
27 for driving a catch system as will be explained below. The two racks are stabilized by
28 means of a bridge 172 connecting their near sides. Said bridge 172 disposes in its middle
29 a docking station 118 for a fleet unit, preferably a service vehicle 6 or a specialized vehi-
30 cle 10, which possesses cameras, and a shaft for mounting the catch system. The cam-
31 eras of the service vehicle 6 or the specialized vehicle 10 can assist fetching storing op-
32 erations of the robotic arm 114 and of the catch system. The down inner corners of the
33 storage racks, the down near corner of the main body 100 and the down part of the rack
34 connecting bridge 172 dispose fastening points, respectively.

1 The catch system 180, which may be placed in different positions at the utility base 4, is
2 shown in Figure 11. Designed as a tape based capture tool (TCT), it mainly consists of a
3 double reel-unreel mechanism 182 mounted on a 3 degree of freedom mechanism (184),
4 two conductive tapes (186) that extend in parallel, and an end piece 188. The end piece
5 188, which is shown in more detail in Fig. 12, is equipped with a camera, a number of
6 light sources, a 3 degree of freedom gripping wrist 190 serving as a capturing mecha-
7 nism. The catch system may be mounted onto a docking base sliding on a shaft attached
8 centrally on the inside of the rack connecting bridge 172, in a way that the cameras of the
9 fleet unit (service vehicle 6 or specialized vehicle 10) docked on the bridge 172 can su-
10 pervise the activities of the same.

11
12 The catch system 180 is detachable from the docking base. Similar docking positions are
13 available at the pressurized compartment of the equipment/storage bay 102 and on the
14 far side of the open equipment bay. The robotic arm 114 can also capture and operate
15 the catch system 180. The end piece 188 further possesses tension sensors for each
16 tape, gyroscopic accelerometer 192, zero to four momentum wheels 194 for attitude con-
17 trol, RF means for transmission of the camera video signal, and a power conversion box
18 196. The power (alternating current) arrives to the end piece 188 by means of the two
19 conductive tapes 186. It is converted to appropriate voltage ratings and distributed where
20 needed. Control signals arrive to the end piece 188 by means of modulating the alternat-
21 ing current transported through the tapes 186. Video link is transmitted from the end
22 piece 188 by means of an RF transmission. The RF signals are received by a central RF
23 reception base.

24
25 Small and medium volume objects for storage may be placed into boxes and boxes are
26 secured in a set of adjacent shelves of parallelogram shape of various sizes assembled
27 out of aluminum or carbon fiber elements or other strong lightweight material. Said
28 shelves may comprise a plurality of temporal adhesive tags at their bottom side that se-
29 cure boxes when in place, even if a plurality of small boxes is stored into a large shelf.
30 The fetching and storing of objects is performed by means of the robotic arm 114, the
31 catch system 180, or other.

32
33 The upper side door 132 of the pro-thalamus 130 (Fig. 5) is reachable by the robotic arm
34 114 and two appropriately positioned catch systems 180. All 5 outer doors 132 have ma-
35 tching interfaces for extension modules. The pro-thalamus 130 houses a round rotating

1 plate equipped with a catch system 180 in the one side of the table, which table can be
2 raised, when an outer door 132 of the pro-thalamus 130 is open, above the upper surface
3 of the equipment/storage bay 102. This way, an object that has been placed on the pro-
4 thalamus table with the help of the catch system 180 can become available to the outside
5 and vice-versa. The catch system 180 can also make available objects to the interior of
6 the main thalamus of the equipment/storage bay 102 when inner door of pro-thalamus
7 130 is open.

8
9 In general, the fleet units of the servicing system 1, in particular the service vehicles 6, do
10 not have redundancy or means for significantly reconfiguring themselves, as regards their
11 hardware. Reconfiguration, repairing, assembling, upgrading is performed at the utility
12 base 4 using special purpose facilities. In addition, the upgrading subsystem is used for
13 conversion of captured foreign objects (CFO). Said CFOs that are of main interest for
14 conversion are non-functional satellites, tanks from spent upper stages, and the like.

15
16 The upgrading subsystem comprises at least: an open equipment bay (OEB) and a pro-
17 tected, or closed equipment-storage bay 102 (CESB). Said OEB is mounted at the far
18 side of the main body 100, through a mechanical electrical and data interface and the
19 CESB is housed in a nitrogen gas pressurized chamber mounted at the west side of the
20 main body 100.

21
22 Said Open Equipment bay "OEB" is used for mechanical or electrical works on the fleet,
23 target spacecraft 2s, or CFO. Conversion operations, be between else processes for ef-
24 fecting access windows on tanks, pipe connecting / disconnecting, rack mounting, equip-
25 ment and cabling network installation.

26
27 Said OEB possesses a plurality of (minimum two) of human size dual robotic arms (pri-
28 mary and redundant)for tool / manipulation with ten finger grips, and arm articulation si-
29 milar to the human (six degrees of freedom). Said dual robotic arms are movable on top
30 of the main body 100 and OEB by means of a mobile base that slides onto a T shaped
31 rail path mounted on their surfaces. The rail path starts at the near edge of the upper
32 surface of the main body 100, crosses the upper surface of the main body 100 with direc-
33 tion towards the OEB. It passes at a sufficient distance from the centre of the main body
34 100 where the robotic arm 114 is mounted. Said rail path then crosses the OEB in a pa-

1 rabolic shape and then passes on top of the CESB having a mounting point on it and
2 continuing in a hemicyclic shape arriving to the upper side of the storage rack.

3
4 Each robotic mobile base is driven by four powered wheels mounted on axis parallel to
5 the rail shaft and pressing against said T rail shaft. Six ball bearings for sliding along the
6 rail head are provided as well as four short ones mounted just below and two wide ones
7 above the T rail head, mounted in parallel to the said horizontal T rail head.

8
9 OEB also possesses a plurality of tools and benches for performing the said services si-
10 milar to what is found in the Ground Segment Support equipment and particularly those
11 that can be exposed to the open space environment with limited shielding.

12
13 The utility base 4 has a stock of accessories for repairing & upgrading the fleet and own
14 subsystems.

15
16 These accessories between else include replacement modules for the hot redundant ele-
17 ments of the utility base 4, (EPS, AOCS, MCP, RF, TT&C) telecommunication modules
18 for UHF and S band and data channel telecommunication modules for C, Ku and Ka band
19 of various output power ratings. They further include attitude control sensors (sun, earth,
20 star based), cameras of various aperture ratings, filters, lenses, endoscopes and telesco-
21 pic probes, towing tethers tether/wire deployment/retracting add-on module as well as
22 sets of retroreflectors, laser diodes, motors, ball bearings, lubricants and lubricating me-
23 ans. Adhesive materials, insulated wires, solar cell spares and fly wheel spares, valves
24 and pipes, thrusters and any other accessory that may be foreseen, need assessment
25 based on a statistical estimation of failure risks of the target spacecraft 2 components and
26 subsystems.

27
28 Said repairing and upgrading tools comprising, between else, of hardware tools set, (la-
29 the, aluminum soldering, etc), electrical tools set (wire connectors, soldering etc), electro-
30 nic tools set (polymeters, palmographs etc.)

31
32 A plurality of tether equipped truss assists in the disassembly process by displacing dis-
33 assembled elements away of the OEB core. Each time a disassembled element is at-
34 tached to the tether the tether is promoted proportionally to the size of the attached ele-

1 ment. To fetch a stored element from the tethered truss the tether is advanced or re-
2 tracted accordingly.

3
4 The utility base 4 also is equipped with active and passive surveillance means.

5
6 These means are used for accurate positioning of objects in the surrounding space and
7 for protection from space debris as well as for assisting cruise or automatic docking of the
8 fleet units. The proximity radar provides a coarse but wide image of the surrounding
9 space objects and the ranging laser a precise determination of distance and position of
10 objects in the surrounding space. The ablating laser destroys small objects or alters the
11 trajectory of larger objects to avoid collision with target spacecraft 2 or utility base 4 or
12 fleet units. It also destroys or steers the particles that escape from the manufacturing pro-
13 cesses to a desired collection point.

14
15 The utility base 4 requires numerous video and Telemetry links to be established for full
16 operation. A gradual process is envisaged to provide the required bandwidth with use also
17 of a resurrected satellite.

18
19 The specialized vehicle 10 may be designed to perform several functions of a so-called
20 escort agent (EA). It basically has the same functional elements in its bus as a typical
21 service vehicle 6 but reinforced in terms of EPS budget and size. It is mainly used for
22 missions with FCO and non-cooperative target spacecraft 2, or with target spacecraft 2
23 where compatibility with its payload has not been achieved.

24
25 Its payload consists of two steerable high gain antennas, for establishing receiving link
26 and retransmitting link to different directions, and cameras. It is designed to assist the
27 docking and other services of a service vehicle 6 by establishing the required surveillance
28 and teleoperation video links with a ground control unit 12 directly or through the utility
29 base 4, or through a third spacecraft. It receives through RF video and TTC signals from
30 a service vehicle 6 or directly from its own cameras and retransmits after amplification.

31
32 A type of escort agents with refueling capability is defined for refugee rescue missions or
33 other high energy orbit missions.

1 The primary operational concept for the servicing system 1 is to reuse the service ve-
2 hicles 6 and other elements of the system in many missions, servicing satellites that are
3 far away in terms of delta velocity potential required to reach them and carry them or
4 maintain their orbit or optimize their trajectory, in particular by using the target spacecraft
5 2 for relaying signals to ground control.

6
7 Nowadays, most of the satellites are operating in the C, Ku and Ka bands. Constructing
8 communication means of very low power in a wide part of these bands to allow compatibi-
9 lity with a large population of satellites is not a problem. In addition to that, the utility base
10 4 comprises means for performing extensive reconfiguration and communication module
11 exchanges so that the service vehicle 6 can become compatible with almost the totality of
12 the current satellite population. Since in short distances of a few meters to hundred me-
13 ters away from the target spacecraft 2, the service vehicle 6 will have to operate the said
14 link, directionality of the antennas is not that important and that there are backwards
15 electromagnetic wave lobes that can be exploited for this cause.

16
17 The advantage of the method is the provision of the needed bandwidth with extremely low
18 powered means. In the case where the powerful communication means of the target
19 spacecraft 2 are used as relay means, the means required in the ground for reception of
20 the service vehicle 6 is as simple as a simple TV receiver in the case of TV satellites.

21
22 Alternatively as it is foreseen in the case where the target spacecraft 2 can not provide
23 the required transmission means another specialized vehicle 10 will perform the task of
24 establishing the link to the ground directly or through a relay, acting as relay satellite in
25 the very vicinity. In this case it might also observe the service vehicle by its own means
26 and provide alternative or the only view point of the service provision to the ground con-
27 trollers.

28
29 The utility base 4, or a third satellite can serve as relay points, but these constitute less
30 preferred options.

31
32 When the service vehicle 6 is in close proximity to the target spacecraft 2 even the tele-
33 metry / telecommand link can be performed through the target spacecraft 2. The method
34 for receiving telecommands at the service vehicle 6 in this case is by listening to the tele-
35 metry of the target spacecraft 2 and select those packets that will be properly identified

1 that are addressed to the service vehicle 6. This will further reduce the energy waste and
2 increase the comfort of the target spacecraft 2 operators.

3
4 Apart from the cases where the service vehicle 6 will act alone or with the help of a ser-
5 vice vehicle 6 a set or behaviors is designed to capitalize on the fact that a plurality of
6 them will be available.

7
8 A method for reaching a signal from a remote place back to the utility base 4 or elsewhe-
9 re can be performed by placing a plurality of service vehicle 6 in distances according to
10 their respective telecommunications means and effect the transmission by means of re-
11 laying from one to the other the signal until it reaches the destination.

12
13 A service vehicle 6 also can carry other service vehicle 6 (towing pushing) docking side by
14 side.

15
16 A set of service vehicles 6 can add on their thrust power and perform a relocation missi-
17 on.

18
19 A set of service vehicles 6 can add their reception transmission means in a formation of a
20 large phased antenna array by positioning themselves according to the desired source of
21 signal or target and coordinated by means of a special Escort agent of the utility base 4 to
22 operate on this mode.

23
24 Several functions may be automated. Most importantly, the docking operation to the utility
25 base 4 and the docking operation to the Engine Module. Advantage of both is the reduced
26 need for teleoperators and resources to establish the video and control link.

27
28 In the case of the docking to engine module or other service vehicle 6 or specialized ve-
29 hicle 10 which is far apart from the utility base 4 the additional advantage is the autonomy
30 achieved. It can be planned at any time. Low level of resources required as docking is
31 performed with optimum fuel usage and provides high level of confidence to the owners of
32 the target spacecraft 2.

33
34 A currently preferred embodiment of the service vehicle 6 is a canonical (rectangular,
35 pentagonal, hexagonal,) rod shaped structure covered with solar panels. In another em-

1 bodiment a pair of solar panels shall be deployable and retractable. When the panels are
2 retracted and secured on the service vehicle 6 surface the service vehicle 6 can be navi-
3 gated as a spin axis stabilized spacecraft. The solar panels will be deployed mainly after
4 docking to a target spacecraft 2 to extend beyond the shade of the satellite that is ser-
5 viced. The service vehicle 6 will have the main thruster in its bottom side while at the top
6 side will have the simple grabble mechanism to grabble the target satellite by the interior
7 of the fuselage.

8
9 The one side of the service vehicle 6 will be capable of performing docking to the utility
10 base 4 or to an Escort vehicle 10 for refueling. The docking and refueling mechanism will
11 be positioned to lower half part of the service vehicle 6 so that the refueling can be possi-
12 ble even if the service vehicle 6 is attached to a target spacecraft 2.

13
14 The service vehicle 6 will be passive as regards the mechanism for the refueling docking
15 but with adequate passive targeting aid (laser retro-reflectors) to ease proximity and semi
16 or fully automated docking. The service vehicle 6 will benefit from the stability of the
17 common docking place. In this way they will be able to switch most of their equipment
18 (momentum wheels, communication payloads, thermal subsystem saving), reducing their
19 wear and increasing their lifetime (form 100% up to 1000%). There will be economy of
20 resources. Fuel consumption reduced to zero, power consumption will be reduced to 2%.
21 The proximity of the service vehicle 6s one to the other can reduce heat dissipation.
22 Further economy. The proximity of the service vehicles 6 can provide inter-alia protection
23 against debris.

24
25 The service vehicles 6 can benefit from a deep-storage mode where some elements
26 could even be extracted for placement under special conditions for extending their lifeti-
27 me. The battery can be stored separately form the service vehicle 6 in appropriate condi-
28 tions. The fuels can be flushed out to avoid corrosion of tanks, pipe lines, valves and
29 other elements form leaks. The tanks could be depressurized to reduce mechanical
30 stress from pressure. The service vehicles 6 can benefit from service vehicle 6-to-Client
31 interface reconfiguration available at the utility base 4. The service vehicle 6 will be re-
32 ceptive to interface configuration changes. It will be possible to change the Communica-
33 tions payload and the grabble mechanism to customize according to client characteristics.
34 The service vehicle 6 can benefit from service vehicle 6 to ground interface reconfigurati-
35 on service available at the utility base 4. The utility base 4 will have the capability to

1 change the configuration characteristics of the service vehicle 6 Interface to the utility
2 base 4. The communication payload may be adjusted depending on the required down
3 link to be used through an Escort-service vehicle 6, through the utility base 4 or through
4 the target spacecraft 2 or otherwise.

5
6 The service vehicle 6 can benefit from mission dependent reconfiguration. The optimum
7 reusability and efficiency will depend on this capability of the utility base 4 to provide this
8 type of reconfiguration. For each mission the fuel reserves will be adjusted, the communi-
9 cation payload will be reconfigured. Transceivers of appropriate strength will be installed
10 and other characteristics will be adjusted (momentum, thruster position)

11
12 When a given spacecraft is close to another spacecraft it can capture the telemetry pro-
13 duced by the first said spacecraft by very simple means as the transmission takes place
14 customarily with a unidirectional antenna and at power levels sufficient to reach earth.

15
16 The telemetry information is transmitted into standardized packets and usually consists of
17 acknowledgments of commands, parameter values from various sources, memory dumps
18 and simple echo messages. A number of these telemetry data packets and specifically
19 these whose content can be forced to particular content by telecommands (like echo te-
20 lemetry, or memory dumps of certain areas) can be selected to carry command data that
21 are addressed to another spacecraft in the range of the telemetry of the first spacecraft.

22
23 This method invented can be used by any spacecraft that can listen-in to the telemetry of
24 the first said spacecraft.

25
26 The method is proposed to be exploited by the plurality of apparatuses here invented and
27 intent to offer services to target spacecraft 2.

28
29 This method, provides merit form the technical and economic point of view. The means
30 used for the first satellite to perform the telecommand link are reused at no extra cost by
31 a plurality of other satellites in a master-slave configuration.

32
33 Additional merit of the invention in the case where the method is applied to control plural-
34 ity of servicing satellites is the assurance provided to the target spacecraft 2 owner that

1 no dangerous commands may be sent to the plurality of the servicing vehicles. He will
2 have full visibility and control to the operations of the servicing vehicles.

3
4 The method is applied by the current invention to make economies in the telecommand
5 reception means and power consumption and to reinforce the confidence to the target
6 spacecraft 2 owners that they have full control of the process. Method of recovering te-
7lemetry information from a satellite whose telemetry means transmit at very low power
8 output or buffering is required or encrypting the telemetry information is required.

9 It is desired in certain circumstances to listen from close distance to the telemetry infor-
10 mation of the target spacecraft 2 either because the telemetry transmission means can
11 not produce a high power signal, either for power constraint/preservation reasons or be-
12 cause of problems in the telemetry transmission means.

13
14 Additional reasons for listening in can be the need to store the telemetry for transmission
15 at a later time. This is especially useful to low earth orbiting satellites that circulate earth
16 and therefore are not all the time in the field of view of a ground station.

17
18 Still another reason is the possible need to encrypt the telemetry before transmission,
19 need that became apparent after the design phase of the target spacecraft 2.

20 In all the above circumstances it will be beneficial to provide a means of retransmitting the
21 telemetry of a target spacecraft 2 at another frequency and at higher power or with a de-
22 lay or in encrypted mode or in any combination of the above.

23
24 The proposed method of invention is the delivery of a service vehicle 6 equipped with the
25 appropriate listen-in, possible buffering, possible encryption and retransmission means
26 preferably to an up-link channel or directly to the ground.

27
28 The choice of way of establishing the feed link depends on the availability of the said up-
29 link. If the direct link is the choice appropriate modification of the standard service vehicle
30 6 shall be performed before mission starts at the utility base 4. The appropriate modifica-
31 tions shall include above standard power generation means, power conditioning means
32 and telemetry retransmission means.

33
34 An uncontrollable target spacecraft 2 that tumbles is very difficult and dangerous to cap-
35 ture because it may damage the spacecraft that attempts approach for the capture.

1
2 A new method is proposed for stabilizing a tumbling spacecraft as follows:

3
4 A pair or service vehicles 6 is equipped with an add-on dual wire deployment / retracting
5 system (WDRS), secured in their lower part of one of their sides. Each of the said
6 WDRSs are equipped with a camera or the pair of service vehicle 6 is escorted by an
7 Escort service vehicle 6 with camera and telecommunication means. The length of the
8 wire (rolled in the said WDRS) shall be several hundred meters in order to allow operation
9 of the escort service vehicle 6 without risk of contamination against the target spacecraft
10 2. The middle of the wire is equipped with a multi anchor apparatus or a net or simply a
11 loop, whatever the case defines as more appropriate that would capture the SC if comes
12 to its path.

13
14 Formation flying of the pair of the service vehicles 6 in proper angle shall enable the tum-
15 bling target spacecraft 2 to be captured. Depending on the moment of inertia of the target
16 spacecraft 2, the service vehicles 6 shall perform well timed, directed and weighted
17 thrusts against the force the wire will effect as it folds around the tumbling spacecraft. A
18 third service vehicle 6 shall observe closely the whole operation. It shall ease the target-
19 ing of the wire capture and determine the risk of damage to the spacecraft after the cap-
20 ture is achieved to direct properly the tumbling attenuation operation.

21
22 In some cases, the transportation of a target spacecraft 2 to higher latitudes, if it has
23 been stacked below the required altitude, or need to go to far longitudes, or need to im-
24 plement a high inclination correction or for other reasons, requires high acceleration- de-
25 celeration maneuvers.

26
27 The said transportation requires stability of the solar panels to avoid deformation or dam-
28 aging them, and to avoid destabilizing libration of the said solar panels during accelera-
29 tion-deceleration phases of the said transportation mission.

30
31 A simple, low material requiring method, is envisaged in order to secure the solar panels
32 from deformation and libration caused by said acceleration/decelerations of the said
33 transportation mission
34

1 A plurality of service vehicles 6 (minimum one, preferably two, more preferably three,
2 most preferably five) equipped each with a wire deployment & retracting system in one
3 side and a sidewise gripe on their front side and a plurality (zero or more) of Engine Mod-
4 ules is deployed. The said Engine modules secure themselves with the help of the said
5 plurality of service vehicle 6 to the fuselages of the said target spacecraft 2. Then, each of
6 the service vehicle 6 in turn secures at the EMs the tip of a wire protruding from the said
7 wire deployment / retracting system. The said service vehicle 6 capture the solar arrays
8 from their tips at the two ends in a manner that the axis of the body of the said service
9 vehicle 6 is perpendicular to the panel surface. After securing the grips the wire retracting
10 systems retract the wires forcing the tips to stability and pressing the lower part of the
11 Engine Module / service vehicle 6 against the said target spacecraft 2. In this configura-
12 tion the service vehicle 6 that are attached to the panel tips can perform thrusts, of which
13 thrusts the vertical component vector of force is effected mainly to the base of the Engine
14 Module and partly to the stiffened solar array panels. Advantageously, the distribution of
15 the force in the three extreme points of the transported body gives excellent moment of
16 inertia and steering capabilities.

17
18 Steering of the panels can add to the maneuverability of the system.

19
20 The thrust history of all thrusters in the system will be archived together with loads (wet or
21 dry), attitude and gyroscopic information, internal acceleration measurements and accel-
22 eration measurements as externally observed by laser ranging from the utility base 4. The
23 totality of this information will be analyzed after every mission and new calibration pa-
24 rameters will be made available. The same parameters minus the ranging information
25 (when away from the utility base 4) will be monitored real time by the thruster owning ob-
26 ject for updating the relative efficiency thruster table.

27
28 For the mass calculation the following method applies when measurement takes place
29 away from the utility base 4. A service vehicle 6 with recently calibrated thrusters attaches
30 to the target spacecraft 2. The solar panels of target spacecraft 2 are secured in the most
31 stable way. A plurality of EA with cameras and ranging lasers position themselves in the
32 space in front of the target spacecraft 2 a little above and a little below its expected tra-
33 jectory at a distance appropriate for the laser means. They point the laser beams towards
34 the target spacecraft 2 and body and they take measurements during a smooth gradual

1 acceleration phase until a few seconds after stopping acceleration. The acceleration shall
2 be smooth and gradual in order to minimize the sloshing of the dry mass.

3
4 The analysis of thrusts data, ranging data, visual data, and simulation analysis on ground
5 can give accurate estimation of the total mass and wet mass specifically.

6
7 The deployment of the servicing system 1 is proposed to start with the launch of a single
8 service vehicle 6 that will make use of the target spacecraft 2 as a relay point therefore
9 not needing neither escort service vehicle 6 for the HBTL nor utility base 4. It may be fol-
10 lowed by one or more service vehicle 6 and/or by an escort service vehicle 6 with refuel-
11 ing capabilities. The refueling escort –service vehicle 6 will provide the required fuel re-
12 serves for the current and part of the upcoming fleet. A possible further refueling escort-
13 service vehicle 6 may precede the arrival of the utility base 4.

14
15 Advantages of this deployment plan is the low initial cost and the high final functionality.

16
17 Three deployment areas are foreseen in the beginning

- 18
19 ■ The Geostationary ring
20 ■ The Low earth orbiting satellites
21 ■ The Medium Earth orbits

22
23 The invention is presented to start providing service in the geostationary ring but the
24 similar apply for the lower to earth orbits and to further missions around other celestial
25 objects or to trajectories between celestial objects.

26
27 This split of functionality between utility base 4, service vehicle 6, EM and EA provides for
28 low mass, low cost, high fuel/dry mass ratio, high maneuverability, long range and oper-
29 ating duration in the service vehicle 6, EA and EM part. On the other had the utility base 4
30 gives to the system high reusability, maintainability, multiple uses, elimination of waste.
31 The system in total provides for efficient, reliable and low cost service operations.

32
33 Main advantage of this architecture is that the service vehicle 6 results in an extremely
34 low dry mass, low cost, agile spacecraft that can service target spacecraft 2 which require
35 large delta velocity potential. Yet main advantage of this element of design is that a dual

1 arm robotic facility is also made available in the context of the system (through the utility
2 base 4 component) allowing for extensive servicing operations.

3
4 A particular advantage of this configuration is that the service vehicle 6 is released by the
5 highly demanding subsystem budgets (performance characteristics), required for a link
6 with earth, which are required only for a small fraction of the lifetime of the service vehicle
7 6 while in the rest of the life time represent dead mass (large overhead in maneuvers).
8 Placing this functional requirement to another element of the system that does not per-
9 form demanding maneuvers (to the utility base 4) it gives high flexibility and low construc-
10 tion and operational costs at the service vehicle 6 part. This fundamental characteristic of
11 the design of the service vehicle 6 is new, unique and useful.

12
13 The service vehicle 6 does not need to have redundancy of most of its sub-systems (po-
14 wer, solar, propulsion). Its only safety characteristic will be that it will have fail-safe me-
15 chanism of its grabble. The service vehicle 6 will capitalize on the presence of utility base
16 4 in the relative proximity and also of the similar service vehicle 6 that will be able to per-
17 form a rescue operation with target the failed service vehicle 6.

18
19 Special Escort-service vehicle 6 will have capability to refuel other service vehicles 6.

20
21 Advantages are: A service vehicle 6 can perform of a heavy mission (high delta velocity)
22 without having to return to the Utility base for refueling and performing again the rendez-
23 vious with the serving spacecraft (mostly manual and difficult task). Instead it can remain
24 attached to its mission and wait for successive installments of fuel by a refueling service
25 vehicle 6 (depending on availability). In this way the required wet mass at the beginning of
26 its mission can be very limited facilitating the rendezvous and docking as well as reducing
27 the cost of orbit maintenance. In the occasion the mission finally required replenishment
28 of the fuel this is achieved by the special Escort-service vehicle 6.

29
30 If a service vehicle 6 runs out of fuel the Escort-service vehicle 6 can replenish and then
31 either separate or perform flight attached one to the other reducing the risk in case of
32 failure of one of the two. The special-service vehicle 6 in the beginning of the deployment
33 of the system may substitute the utility base 4.

1 The service vehicle 6 will take advantage of the capabilities of the utility base 4 to perform
2 reconfiguration operations. It will be able to change communication payload and grabble
3 characteristics in order to fit for service for a variety of potential target spacecraft 2.

4
5 The service vehicle 6 shall be able to enter an idle storage mode when docked on the
6 utility base 4 or to another service vehicle 6. This will conserve the wear of most subsys-
7 tems even the structure (by thermal cycles) and reduce the consumption of energy. This
8 will become possible by the presence of the utility base 4 or an Escort-service vehicle 6.

9
10 A simplified version of the service vehicle 6 is the Engine Module that does not have ca-
11 meras and the like for performing a navigation and docking. Is put in place on an target
12 spacecraft 2 with the help of a service vehicle 6 or EA and remains there to perform stati-
13 on keeping and inclination maneuvers until it will require fuel replenishment. In this case,
14 a service vehicle 6 with capability of automatic docking on the Engine Module will dock
15 and provide fuel for another term of the mission.

Abstract

A service vehicle (6) for performing in-space operations on a selected target spacecraft (2), shall be provided such that a particularly versatile and flexible service for performing in-space operations on the target spacecraft (2) is possible. Furthermore, a servicing system (1) and a method for in-space servicing of spacecraft (2) shall be provided. With this object, according to the invention the service vehicle (6) comprises a communication module (60) which with respect to its transmission characteristics is configurable in order to meet given receiver parameters of said selected target spacecraft (2). Furthermore, according to the present invention the selected target spacecraft (2) is used to relay transmitted signals or information from the service vehicle (6) to a ground control module (12).

Fig. 1

Reference Numerals

1	servicing element
2	target spacecraft (Utility Agent, UA)
4	utility base
6	service vehicle
8	engine module
10	specialized vehicle
12	controll module
14, 16	arrows
20	main body
22	propulsion system
24	docking system
25	exhaust system
26	cameras
28	built-in communication system
30	control system
32	dashed line
34	receiver
36	emitter
38	arrow
40	hollow axle
42	action axle
44	fail-safe mechanism
46	double arrow opening tip
48	surface
50	nozzle ring
52	exhaust channel
54	combustion chamber
60	communication module
62	multiplexer
64	modulator
66	transmitter
68	controller module
70	encoder

72	camera
74	proximity sensor
76	arrow
78	control module
80	receiver
82	arrow
84	demodulator
86	docking subsystem
88	branch line
90	retroreflectors
92	refueling module
100	main body
102	equipment/storage bay
104	delivery/refueling rack
106	storage module
108	primary solar panels
110	secondary solar panels
112	support grid
114	robotic arm
116	reflectors
118	docking station
120	actual arm
122	wrist element
130	pressurization controlled prothalamus
132	outer doors
134	internal doors
140	three-arm small-sized robots
142	horizontally secured axis
144	axis
146	conductive surfaces
148	human-like manipulation arms
150	arm
152	two finger gripper
154	table
156	storage racks

160	utility outlets
162	tanks
166	side surface
168	upper surface
170	mechanical interface
172	bridge
180	catch system
182	double reel-unreel mechanism
184	freedom mechanism
186	conductive tapes
188	end piece
190	gripping wrist
192	gyroscopic acceleraometer
194	momentum wheels
196	power conversion box

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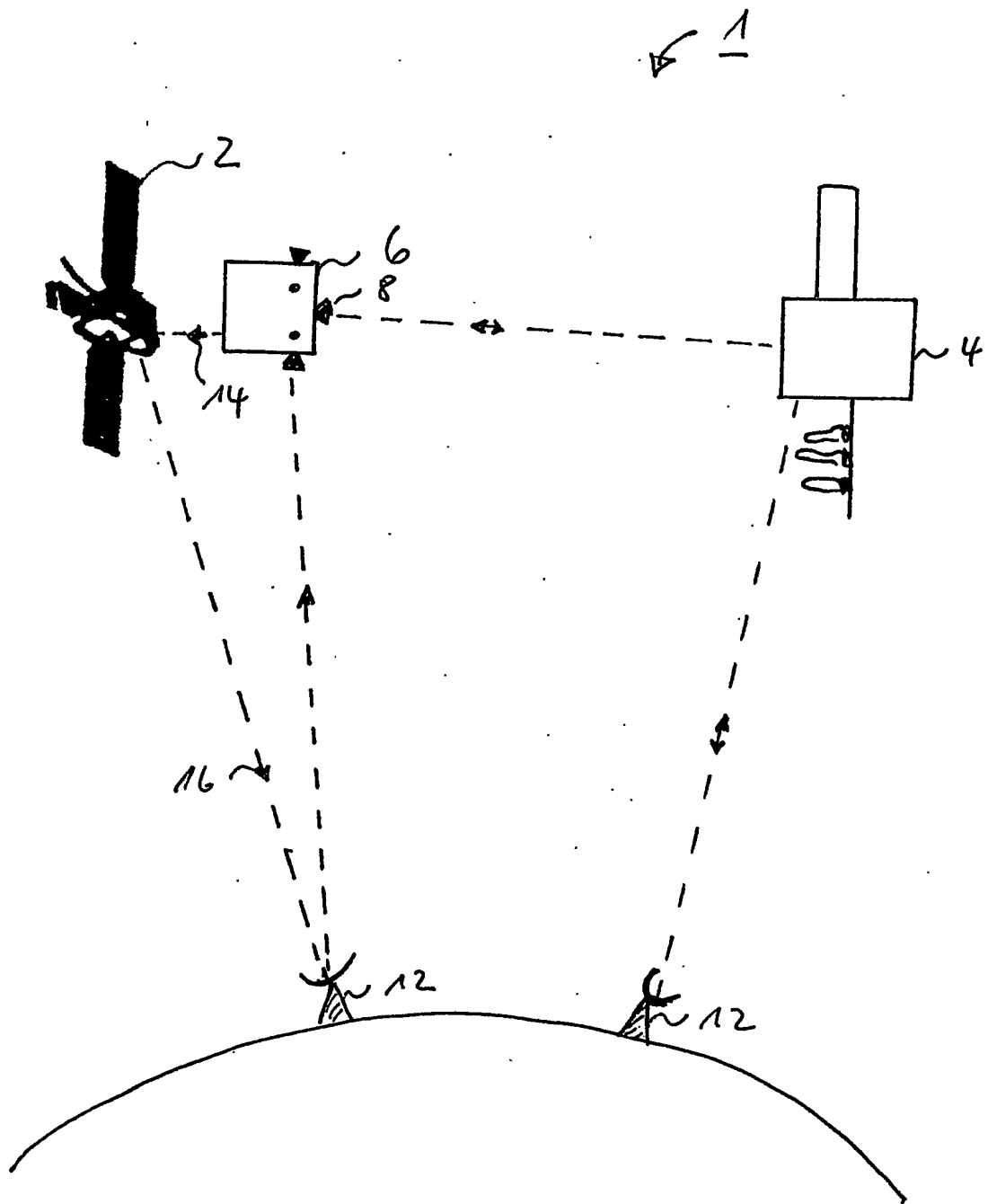
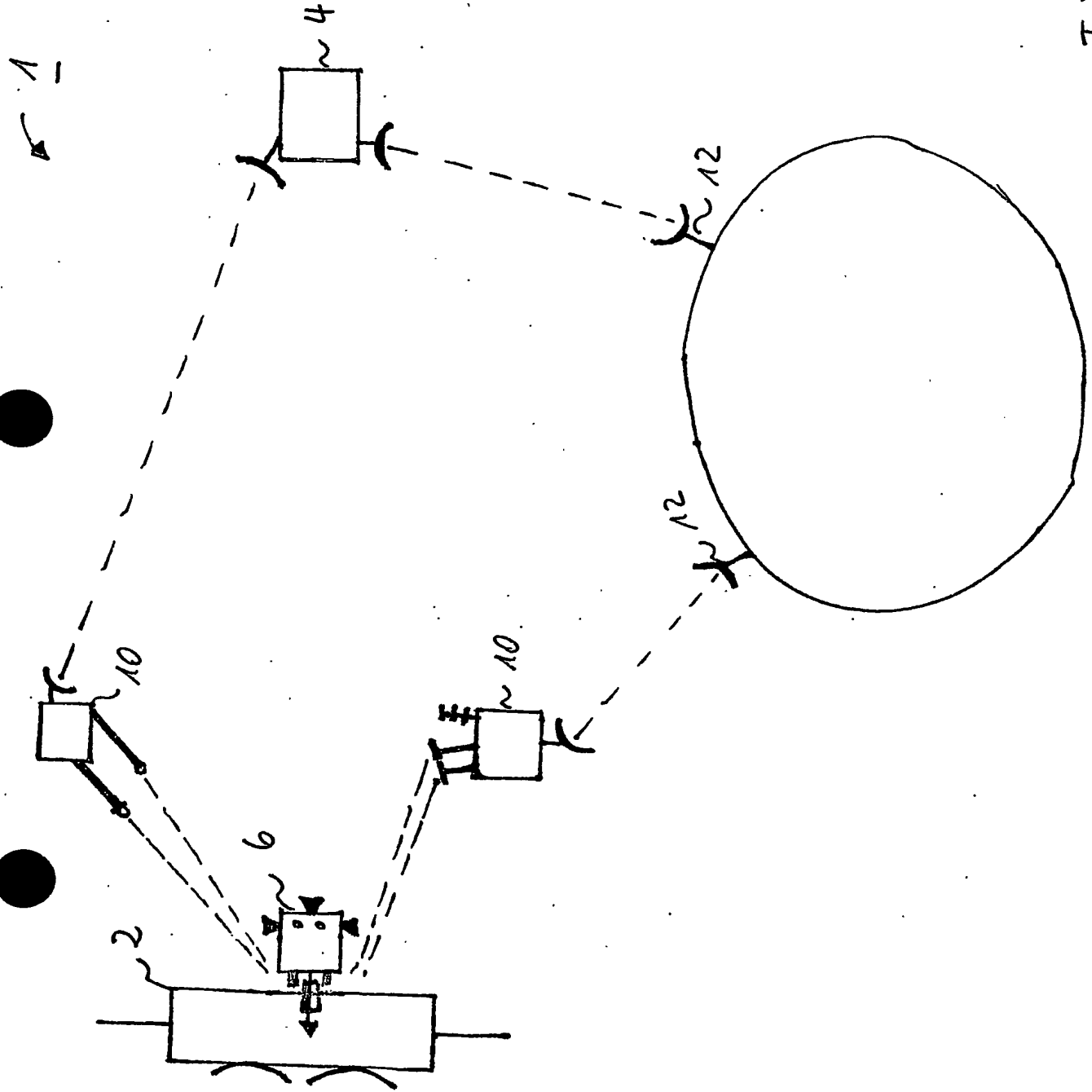


Fig. 1

Fig. 2



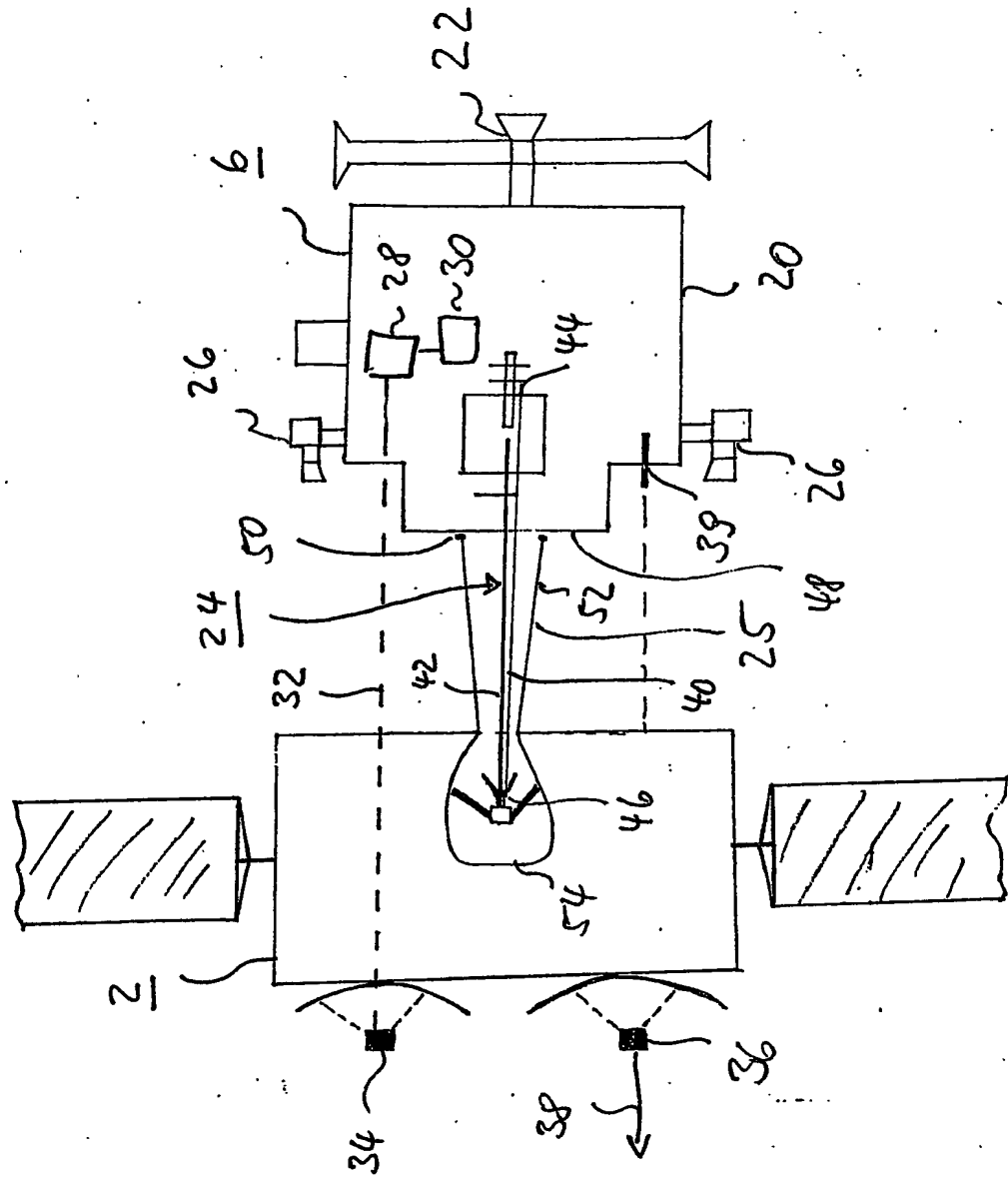


Fig. 3

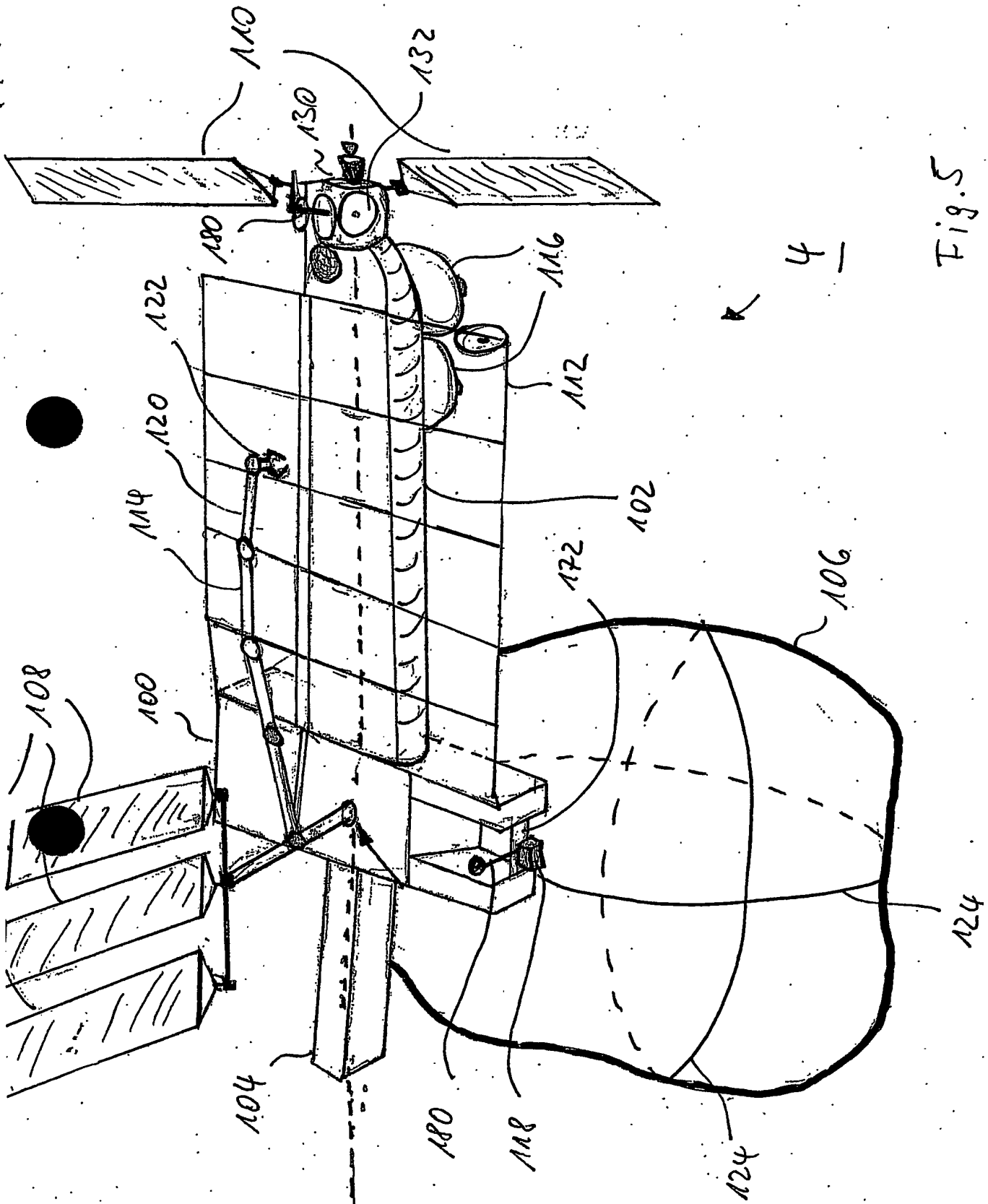


Fig. 5

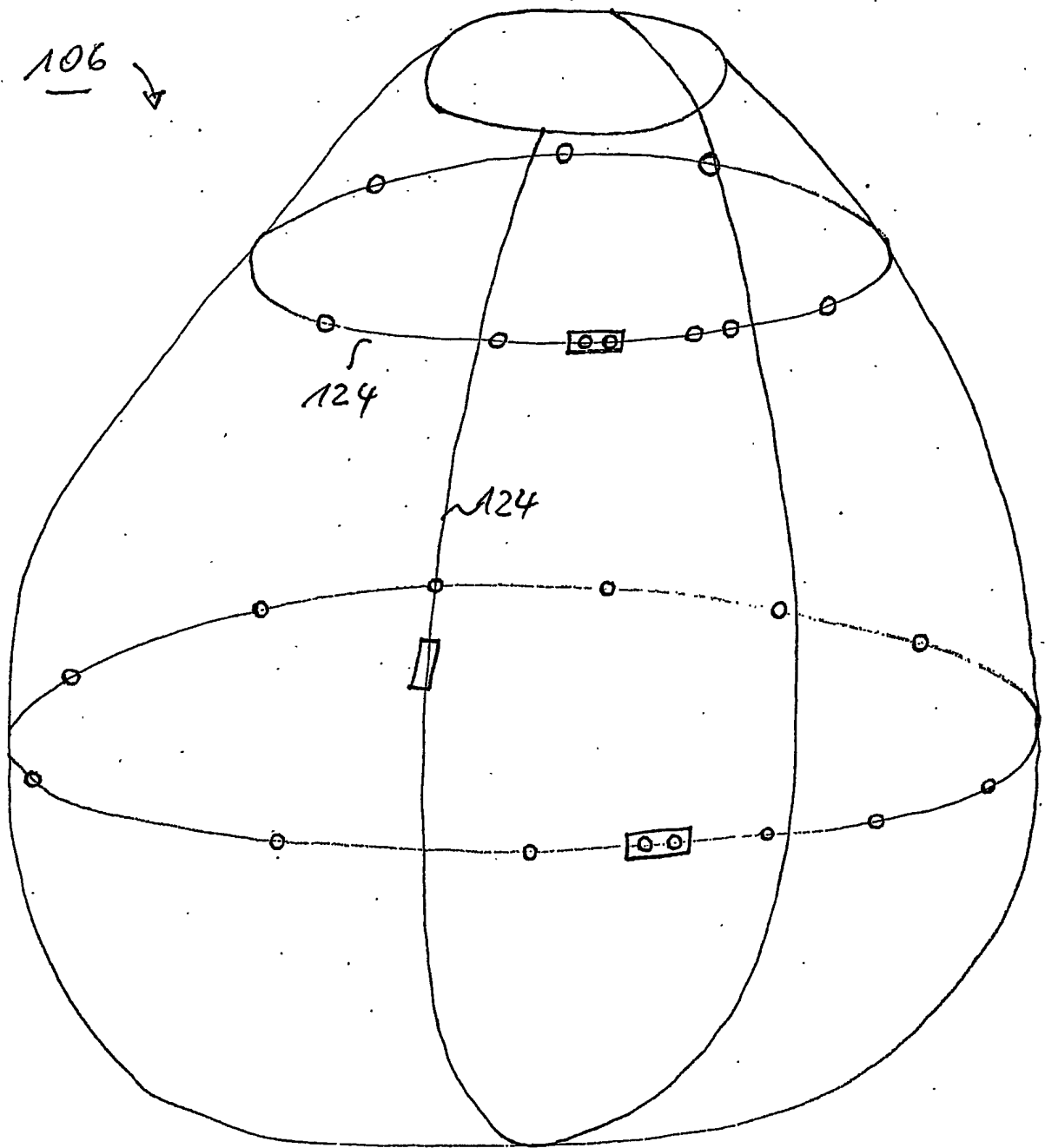


Fig. 6a

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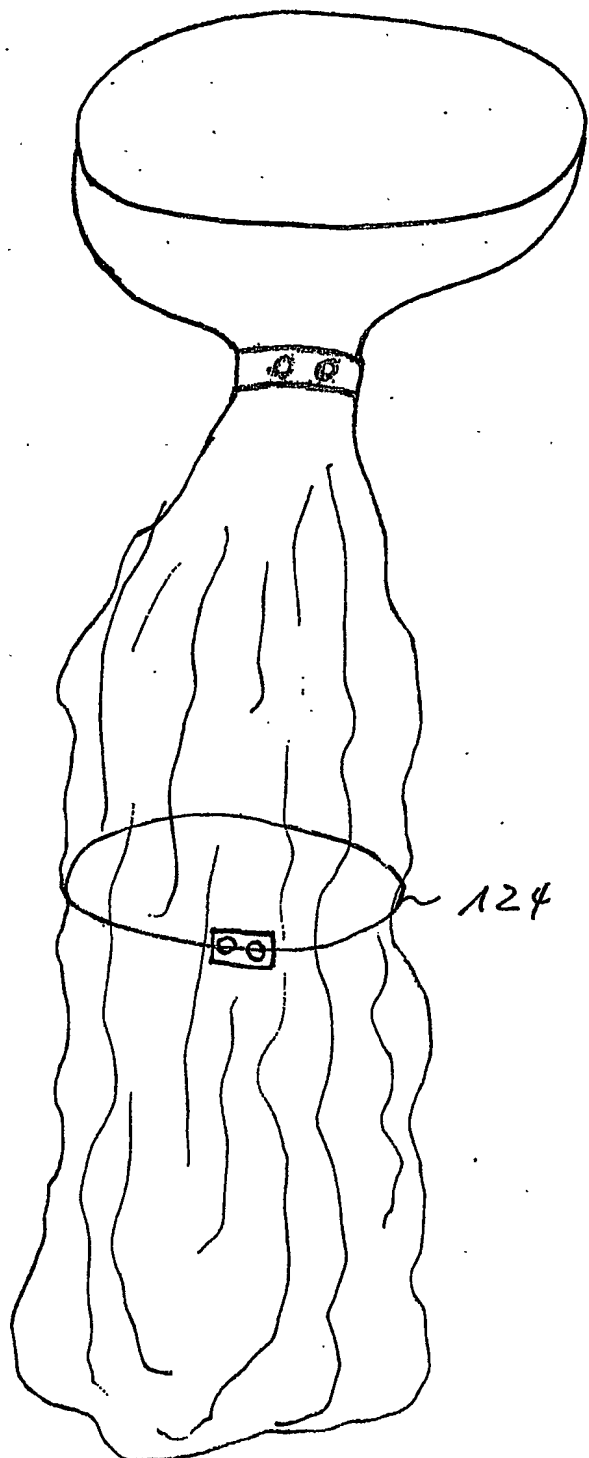


Fig. 66

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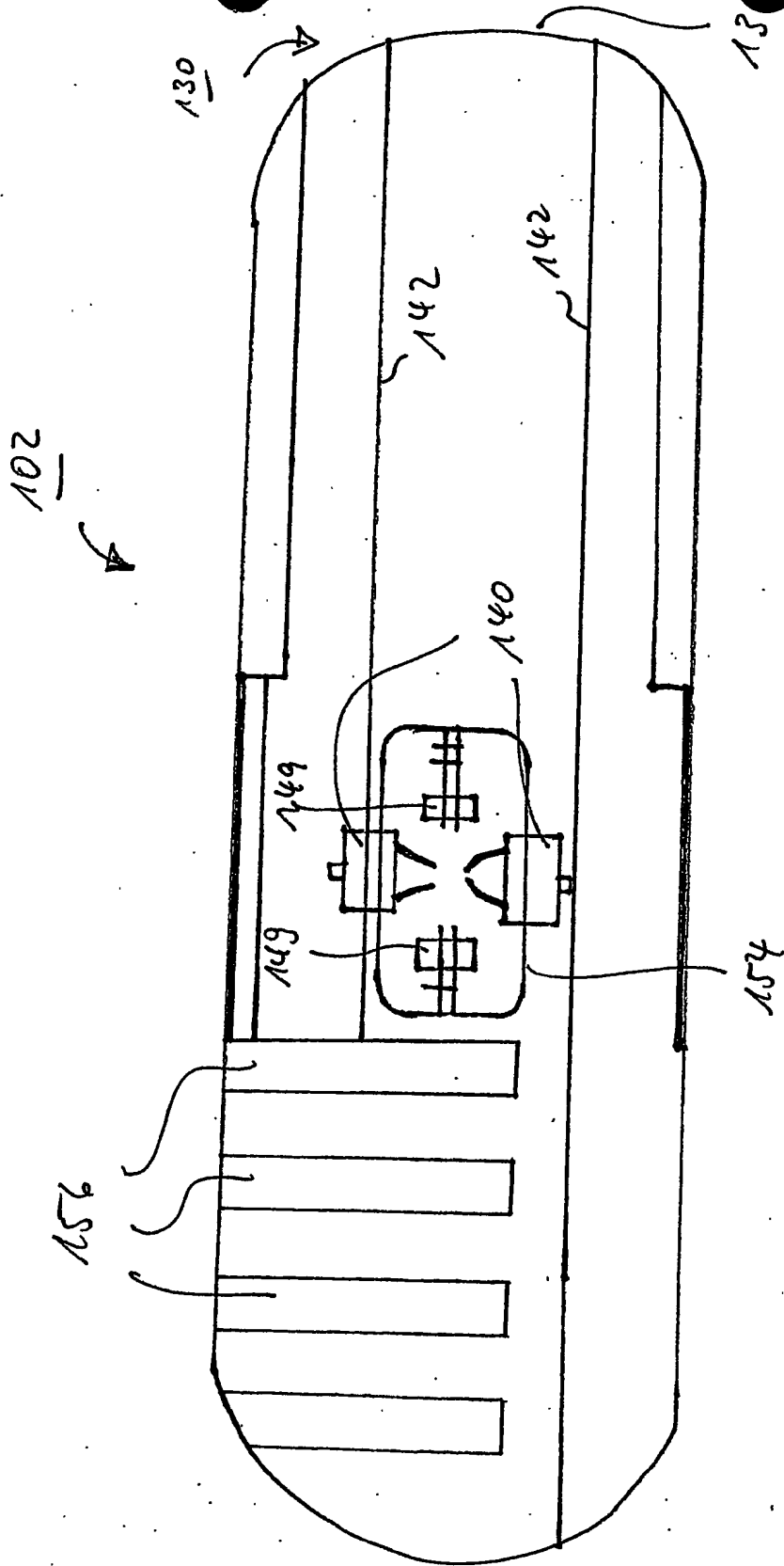
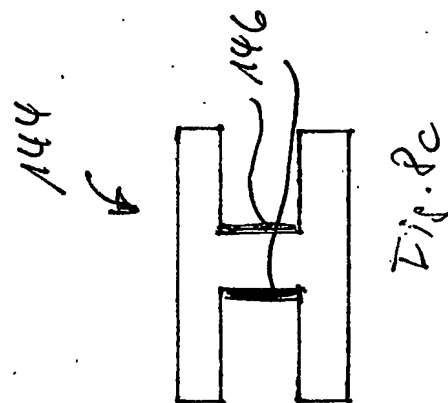
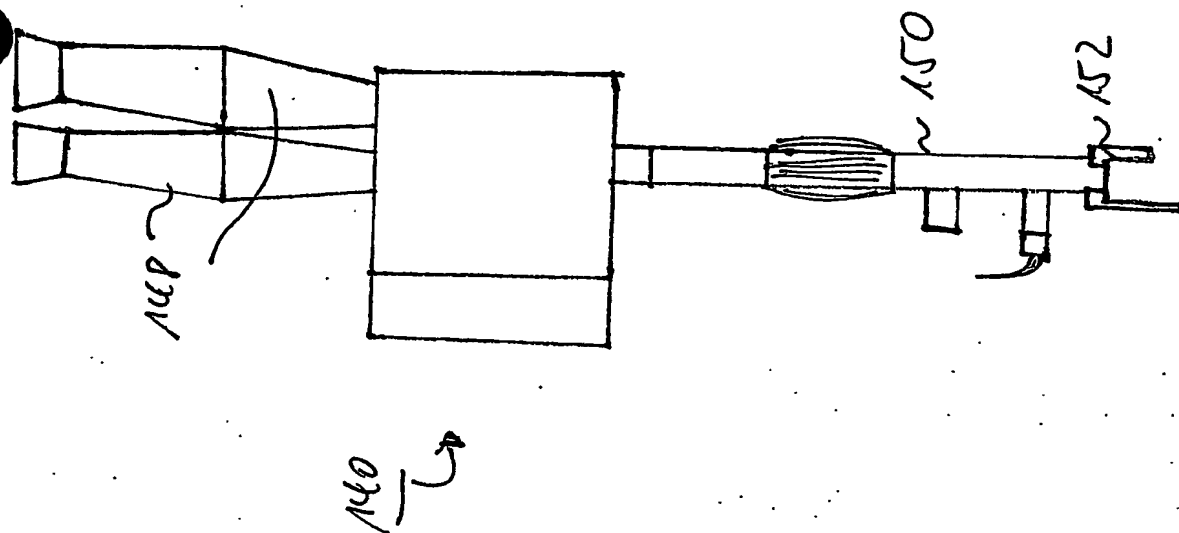
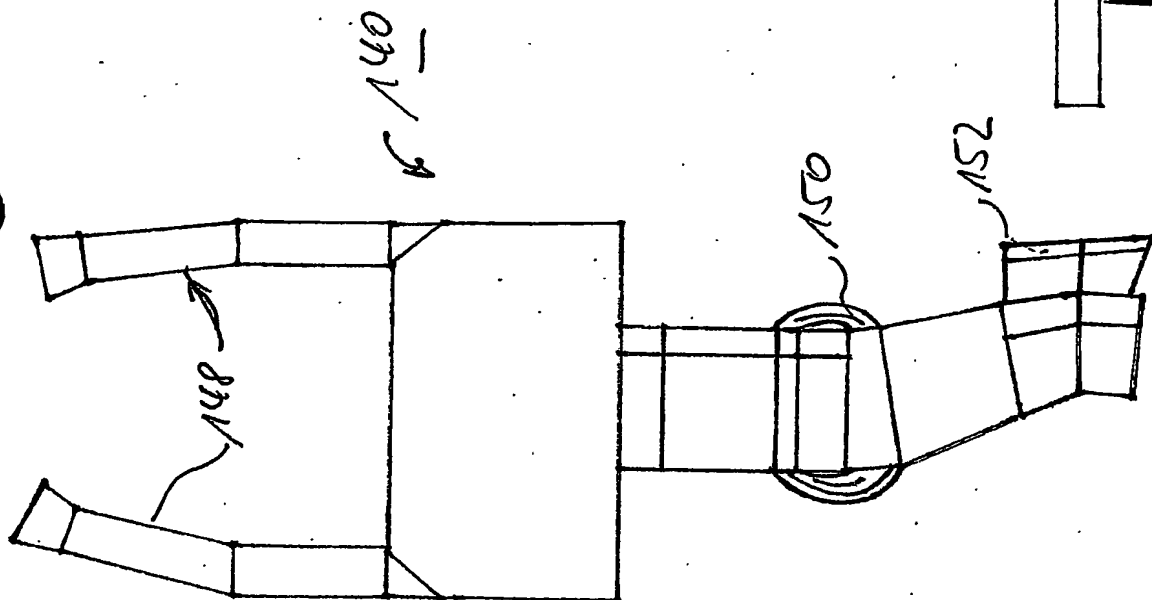


Fig. 7



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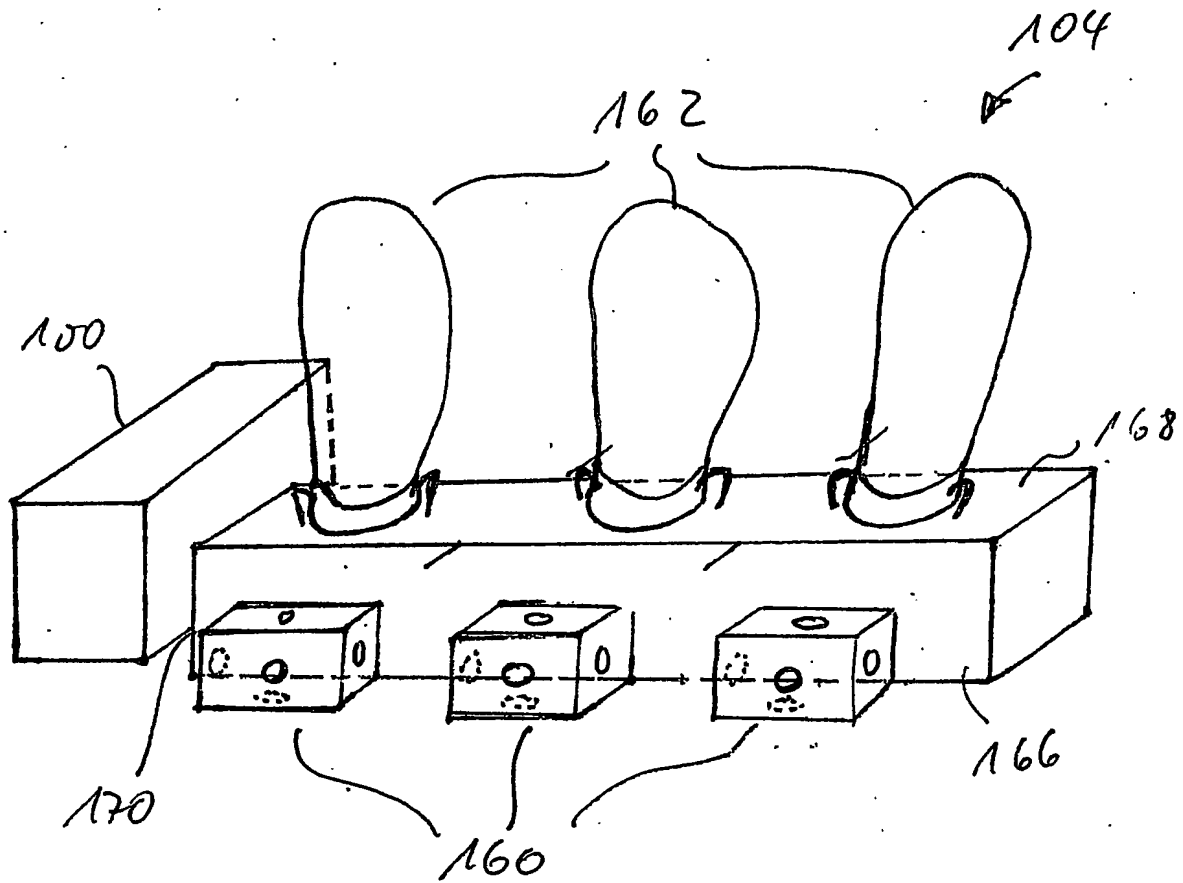


Fig. 9

Fig. 10a

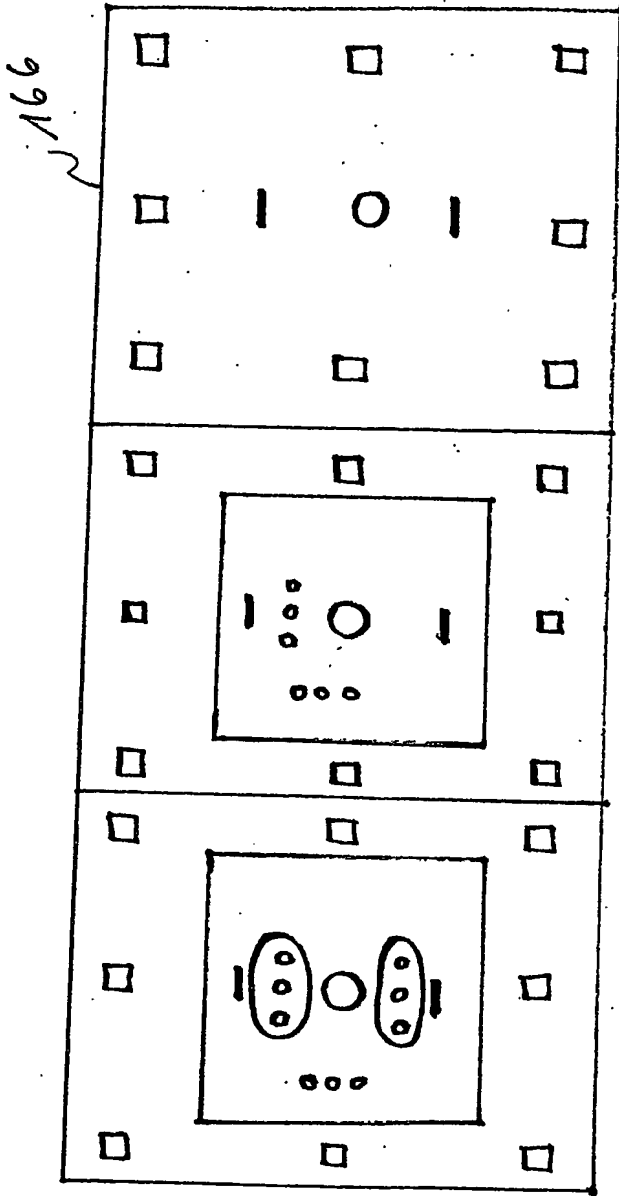
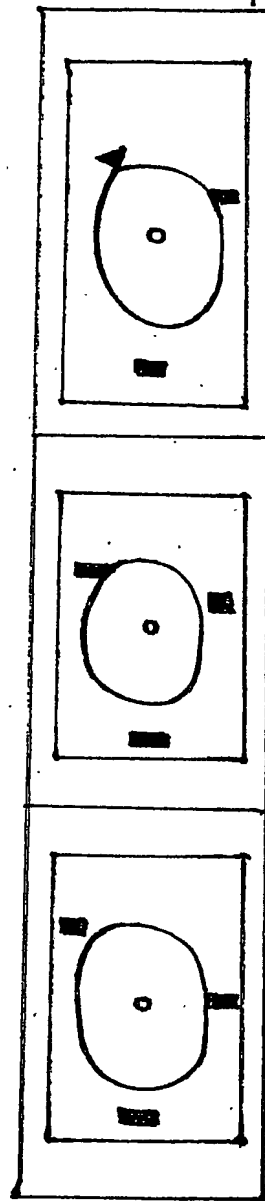


Fig. 10b



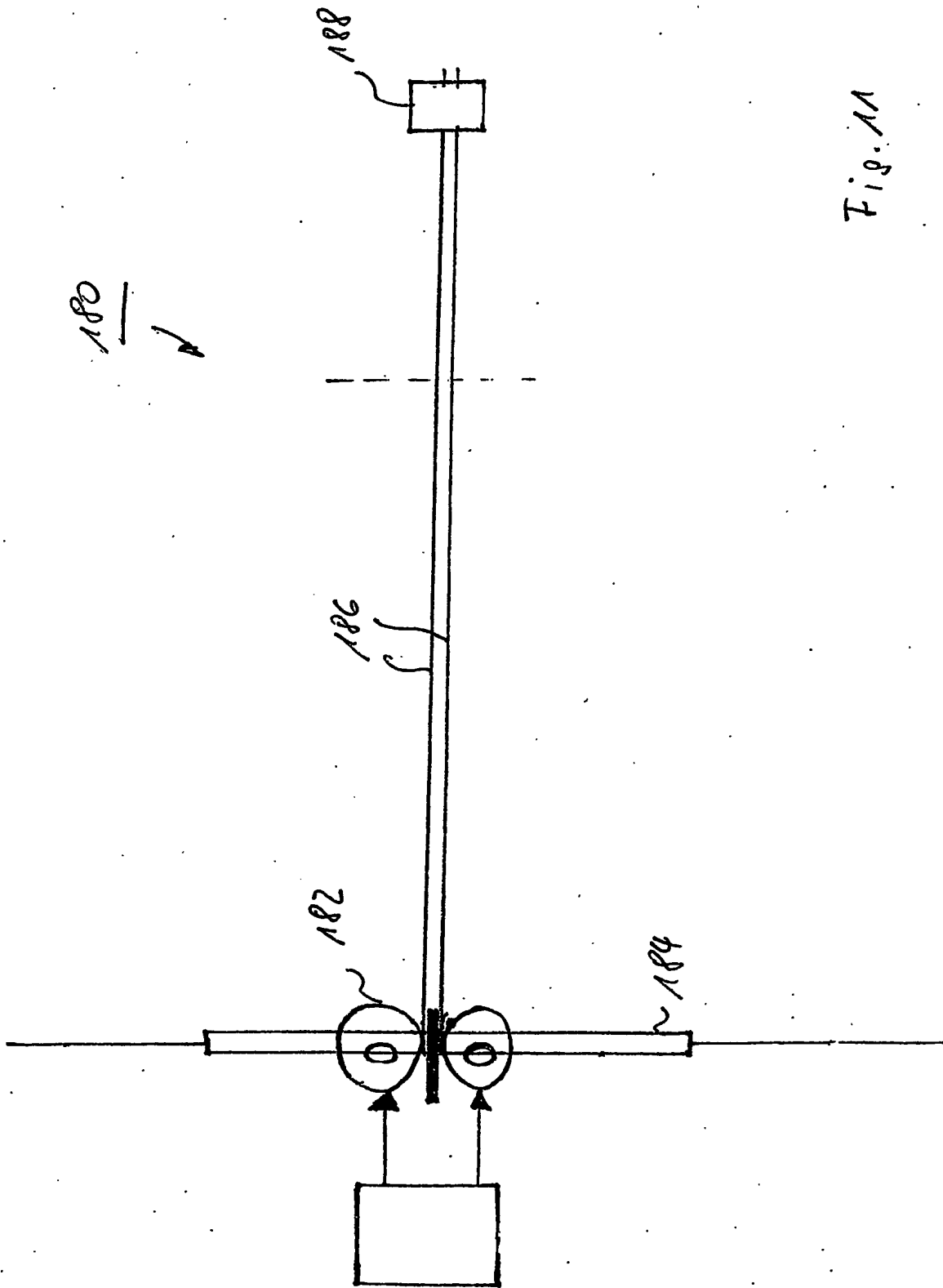


Fig. 11

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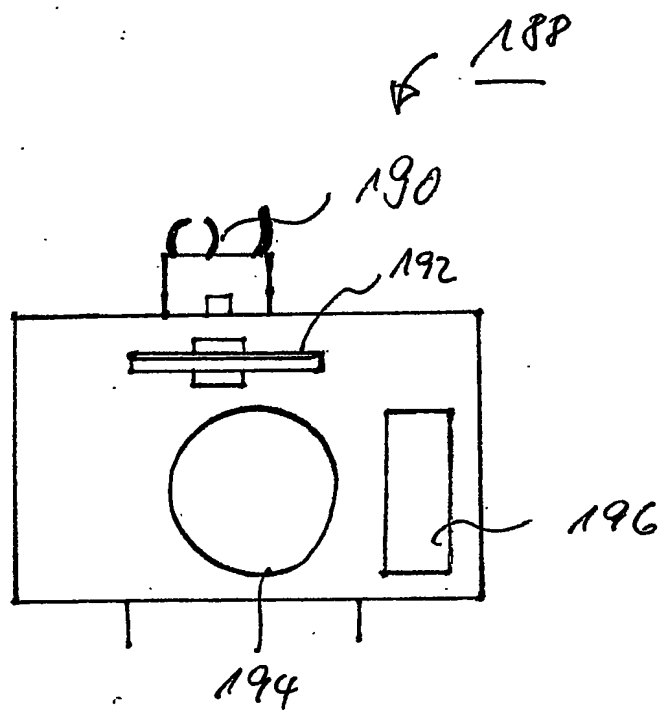


Fig. 12

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